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Kim et al.

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(54) **SOLAR CELL MODULE**

(71) Applicant: **LG ELECTRONICS INC.**, Seoul (KR)

(72) Inventors: **Jongdae Kim**, Seoul (KR); **Kisu Kim**, Seoul (KR)

(73) Assignee: **LG ELECTRONICS INC.**, Seoul (KR)

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(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**

H01L 31/05 (2014.01)
H01L 31/0224 (2006.01)

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(52) **U.S. Cl.**

CPC ... **H01L 31/0504** (2013.01); **H01L 31/022425** (2013.01); **H01L 31/0512** (2013.01); **H01L 31/068** (2013.01); **H01L 31/1804** (2013.01); **Y02E 10/547** (2013.01); **Y02P 70/521** (2015.11)

(58) **Field of Classification Search**

USPC 136/252, 255, 256, 251
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,638,708 B2 * 12/2009 Fork et al. 136/246
2005/0221613 A1 10/2005 Ozaki et al.

(Continued)

FOREIGN PATENT DOCUMENTS

EP 2020688 2/2009
EP 2058868 5/2009

(Continued)

OTHER PUBLICATIONS

Hayashi et al. WO 2011046176A1, English Translation of the specification.

(Continued)

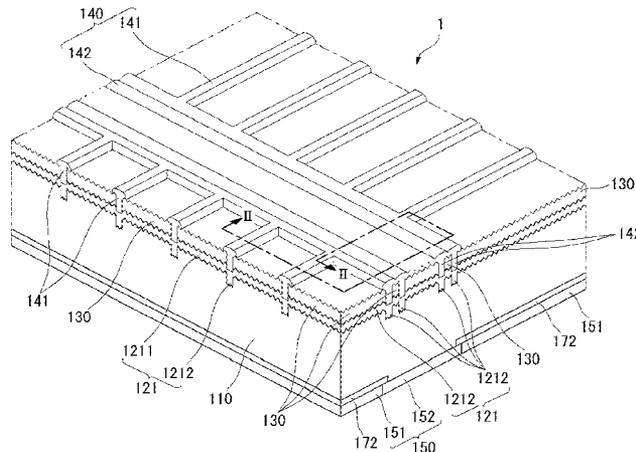
Primary Examiner — Susan D Leong

(74) *Attorney, Agent, or Firm* — Dentons US LLP

(57) **ABSTRACT**

A solar cell module includes a plurality of solar cells each comprising a substrate, an emitter region placed at the substrate, an anti-reflection region placed on the emitter region, first electrodes placed on the substrate, first bus bars placed on the substrate and connected to the first electrodes, second electrodes placed on the substrate, and second bus bars placed on the substrate and connected to the second electrodes. The anti-reflection region includes a first opening region through which part of the emitter region is exposed and one or more second opening regions through which part of the emitter region is exposed. The first electrode is connected to the exposed emitter region of the first opening region through the anti-reflection region by metal plating and the first bus bar is connected to the exposed emitter region of one or more second opening regions through the anti-reflection region by metal plating. An interconnector electrically connects the first bus bar and the first bus bar or the second bus bar of an adjacent solar cell of the plurality of solar cells.

23 Claims, 22 Drawing Sheets



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H01L 31/068 (2012.01)
H01L 31/18 (2006.01)

FOREIGN PATENT DOCUMENTS

EP	2337081	A2	6/2011
EP	2421055	A2	2/2012
EP	2490265		8/2012
JP	2002373996		12/2002
JP	2004266023		9/2004
JP	2008153670	A	7/2008
JP	2009509353	A	3/2009
JP	2013175703	A	9/2013
WO	2006005116		1/2006
WO	2010/126038	A1	11/2010
WO	2011046176		4/2011
WO	2011152319	A1	12/2011
WO	2011162406	A1	12/2011
WO	2013090570	A1	6/2013

(56) **References Cited**

U.S. PATENT DOCUMENTS

2007/0095387	A1*	5/2007	Fujii	H01L 31/0512 136/251
2007/0144578	A1	6/2007	Cunningham et al.	
2009/0032081	A1	2/2009	Saita et al.	
2009/0194151	A1	8/2009	Ishikawa et al.	
2009/0223549	A1	9/2009	Ounadjela et al.	
2009/0260684	A1	10/2009	You	
2010/0015750	A1	1/2010	Shen et al.	
2010/0154873	A1	6/2010	Hilali et al.	
2010/0218821	A1	9/2010	Kim et al.	
2010/0224228	A1	9/2010	Kim et al.	
2010/0319766	A1	12/2010	Suh	
2010/0319770	A1	12/2010	Lee et al.	
2011/0088746	A1	4/2011	Hong et al.	
2011/0308608	A1*	12/2011	Shim	H01L 31/02168 136/258
2011/0315188	A1	12/2011	Hong et al.	
2012/0298171	A1	11/2012	Huang et al.	

OTHER PUBLICATIONS

Kobamoto WO 2010126038A1, English Translation of the specification.

* cited by examiner

FIG. 1

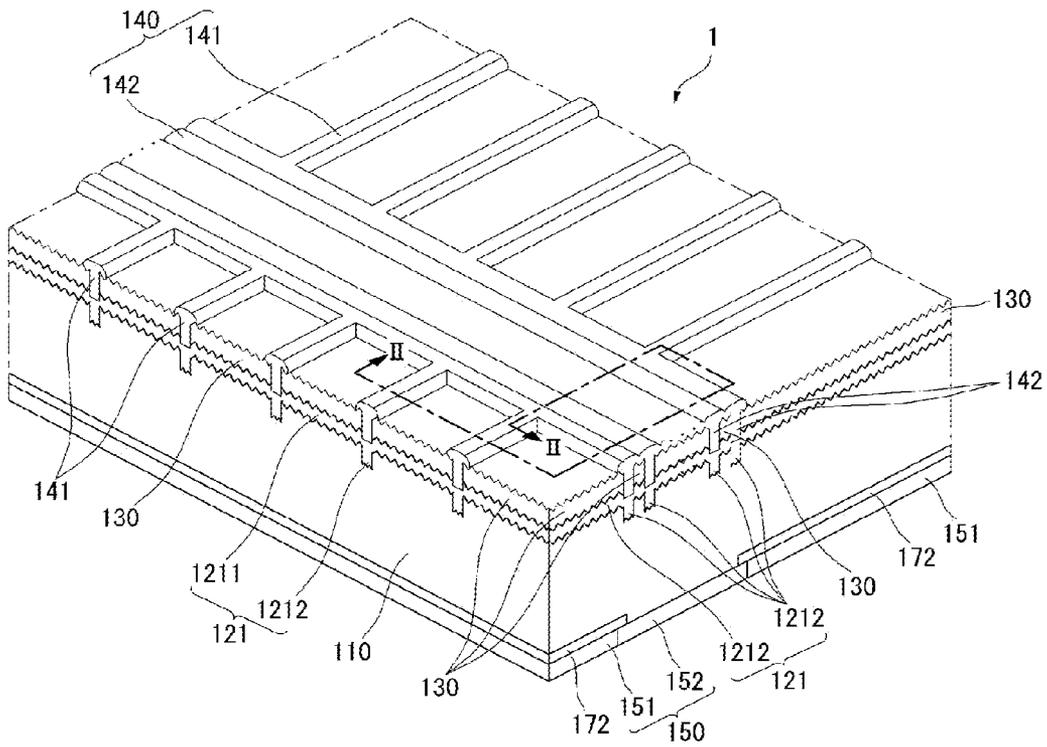
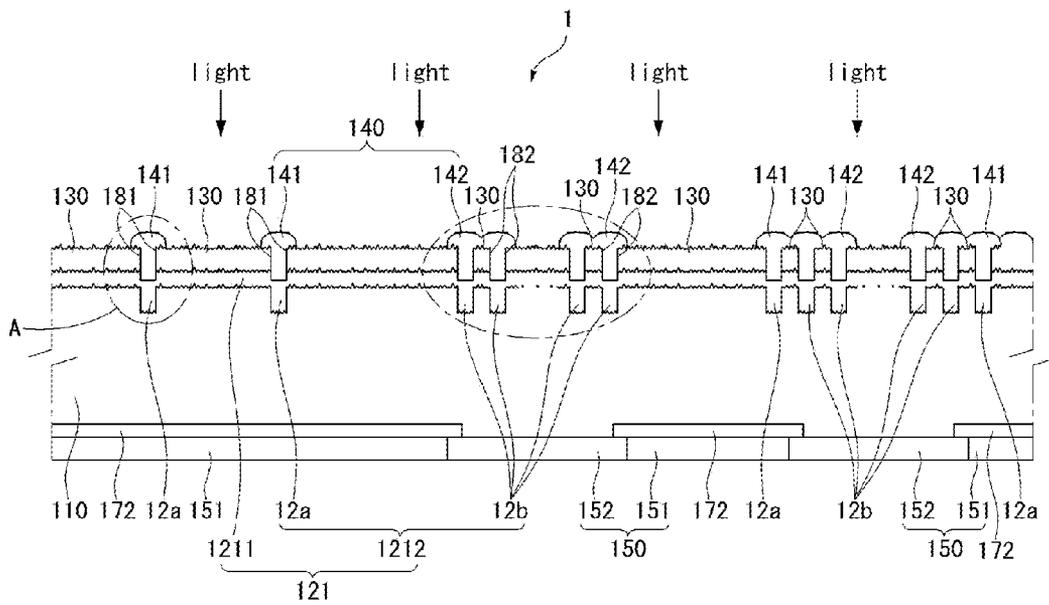


FIG. 2



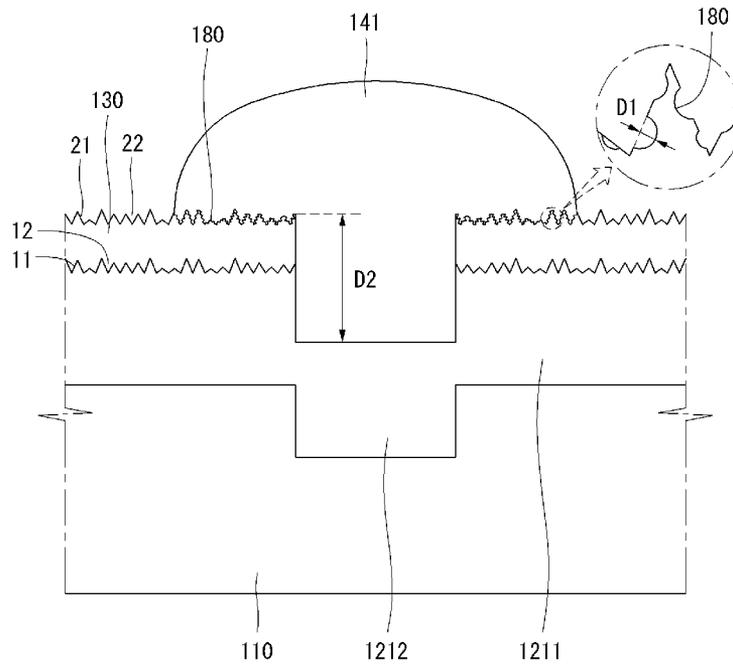


FIG. 3(a)

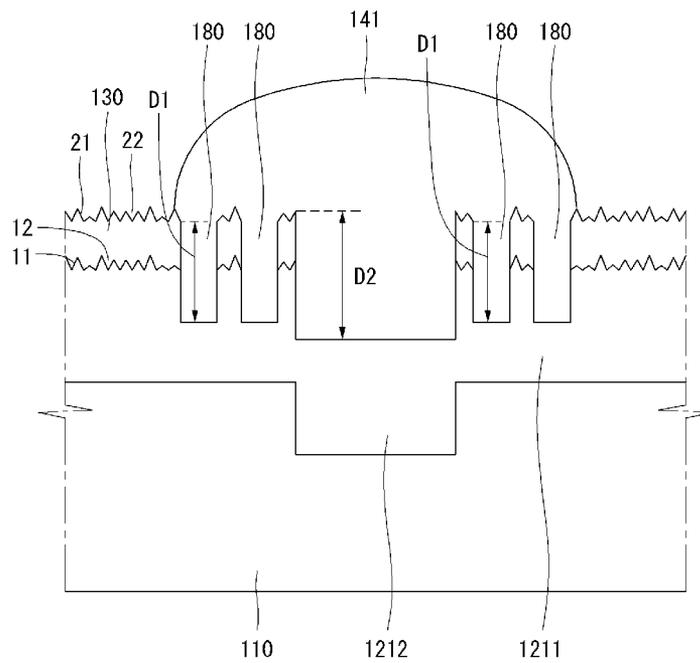


FIG. 3(b)

FIG. 4(a)

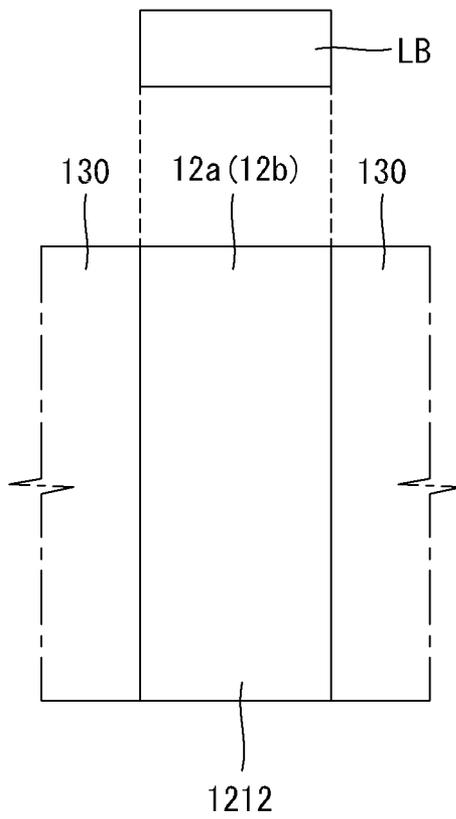


FIG. 4(b)

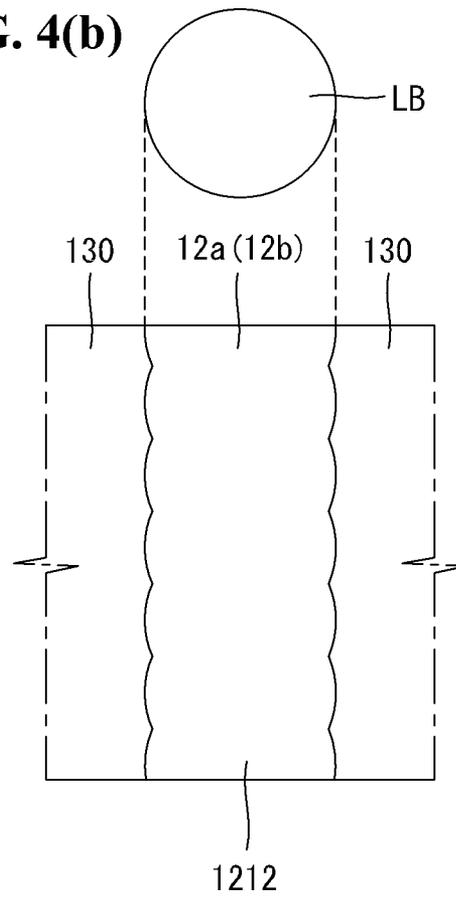


FIG. 5

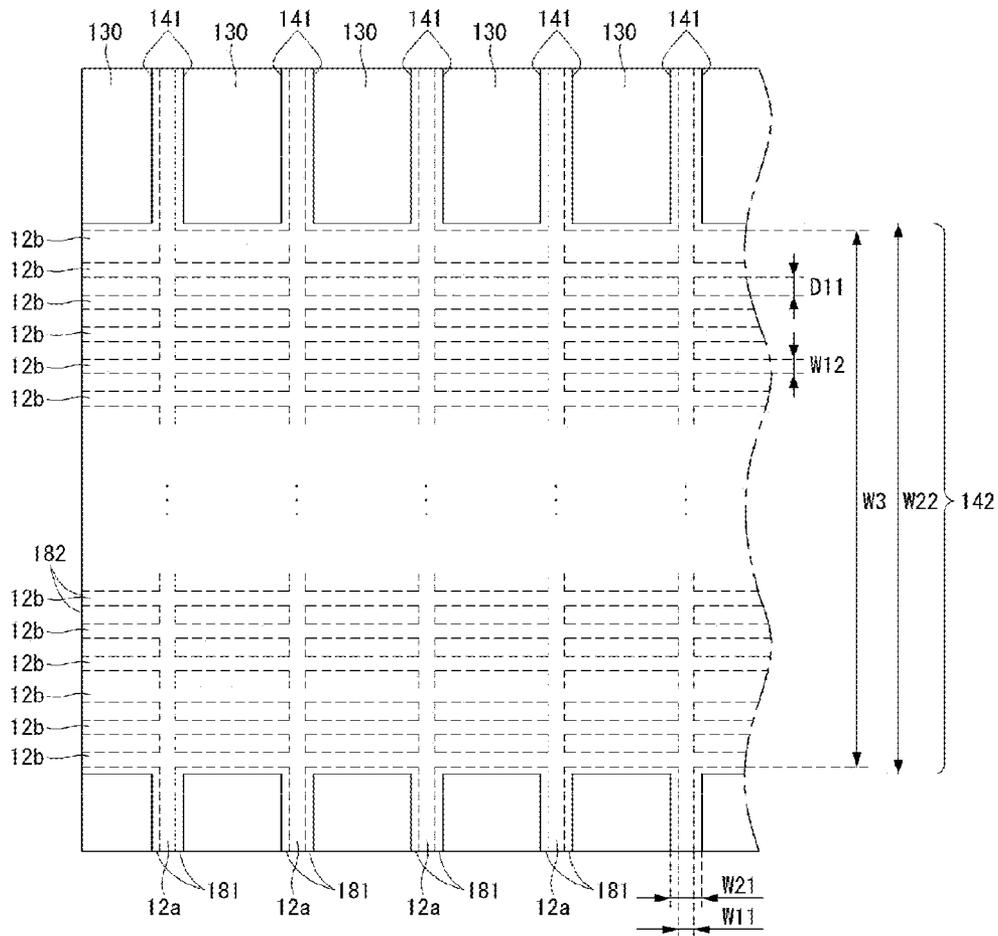


FIG. 6

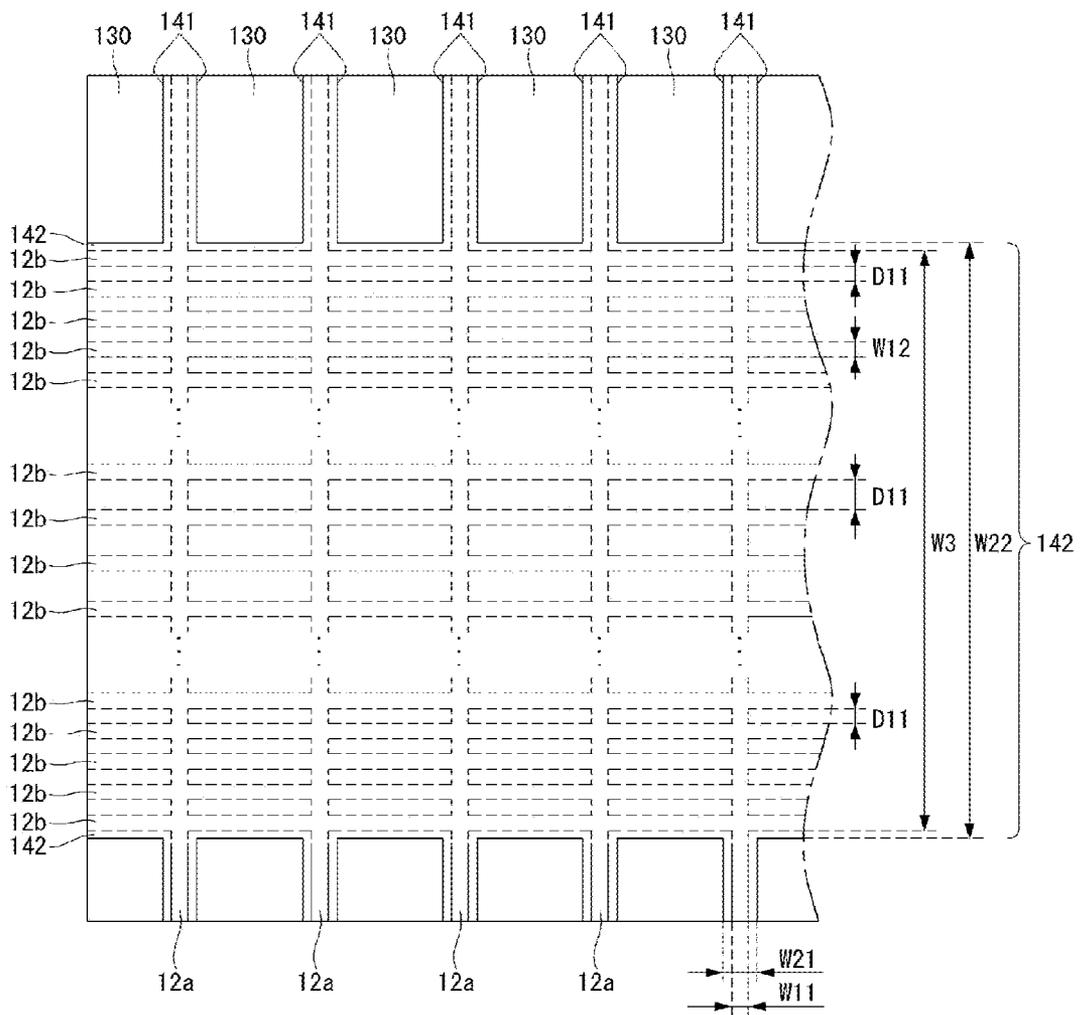


FIG. 7

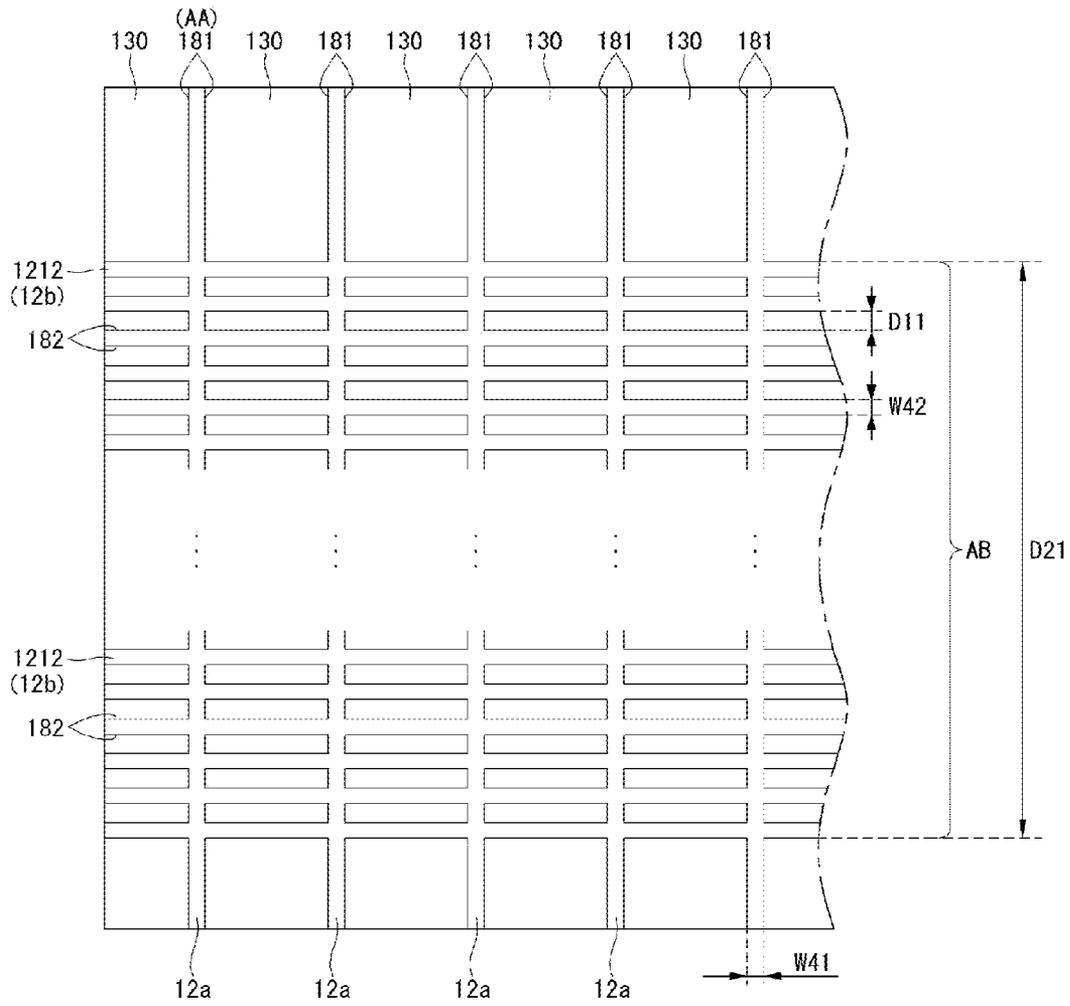


FIG. 8

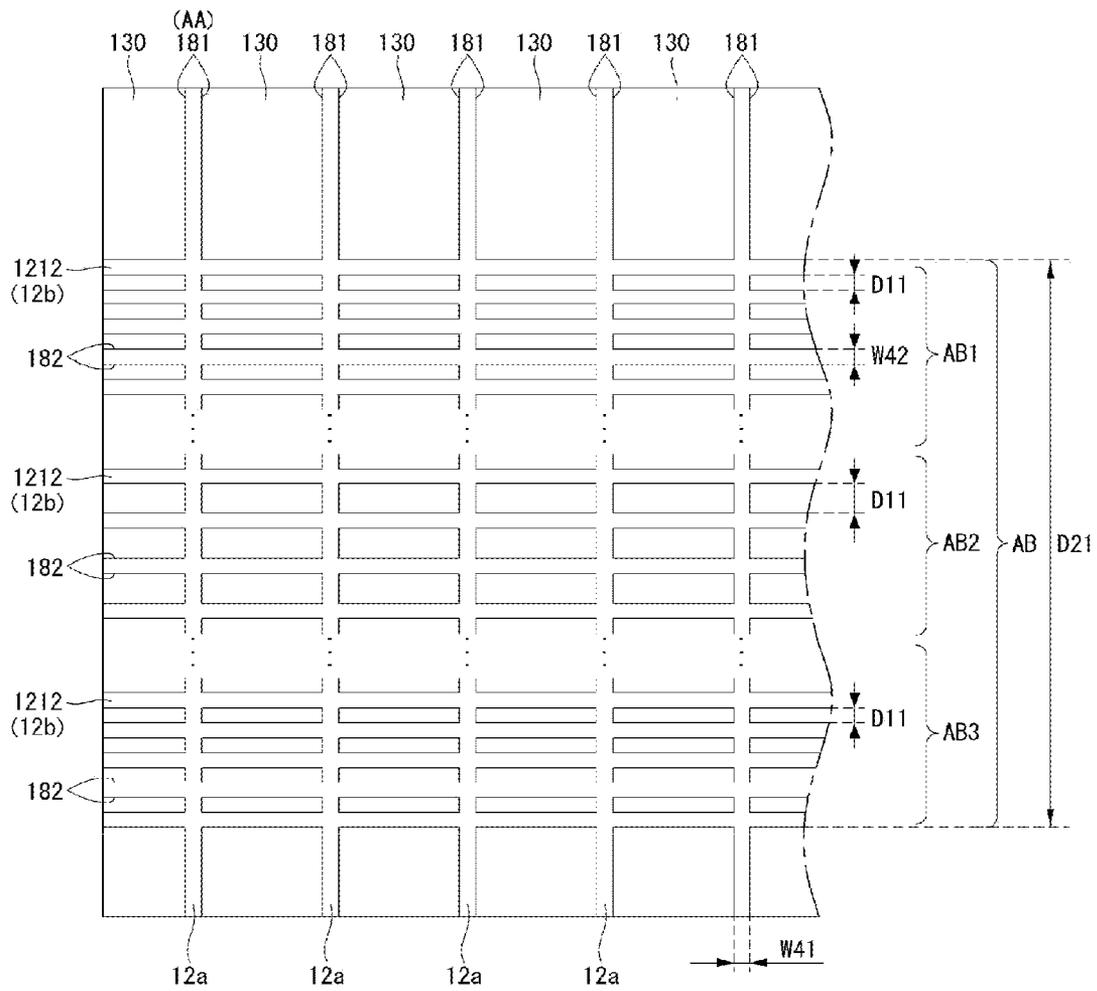


FIG. 9

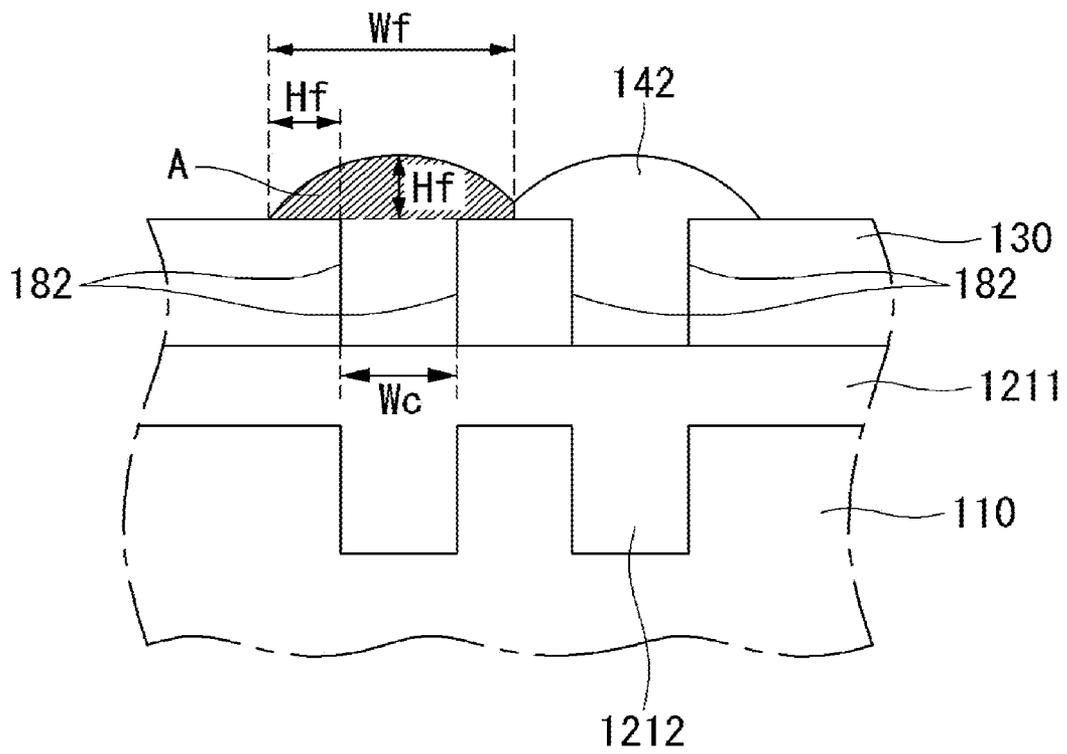


FIG. 10(a)

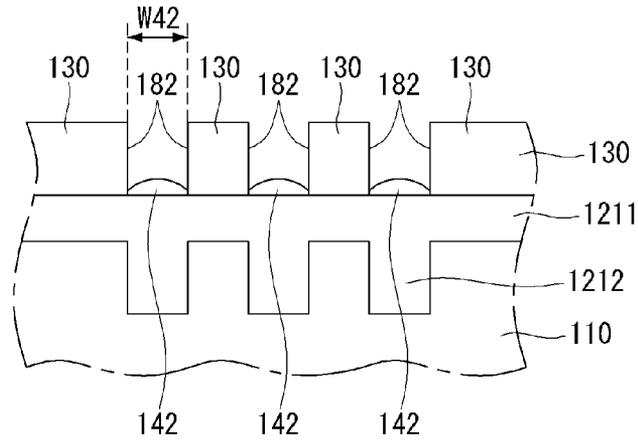


FIG. 10(b)

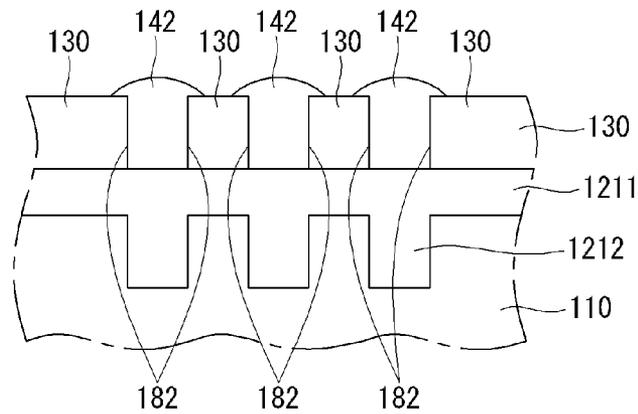


FIG. 10(c)

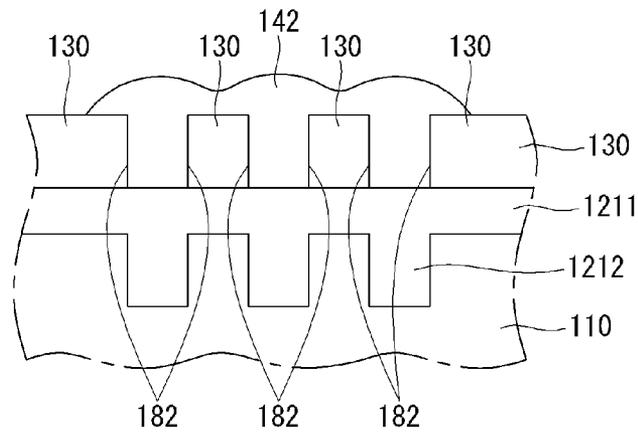


FIG. 11

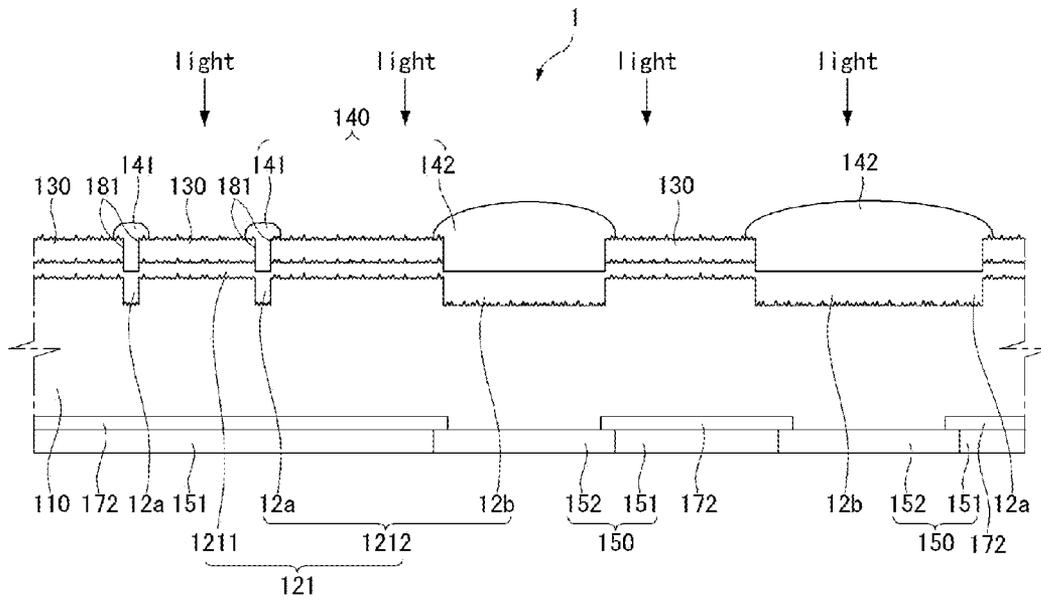


FIG. 12A

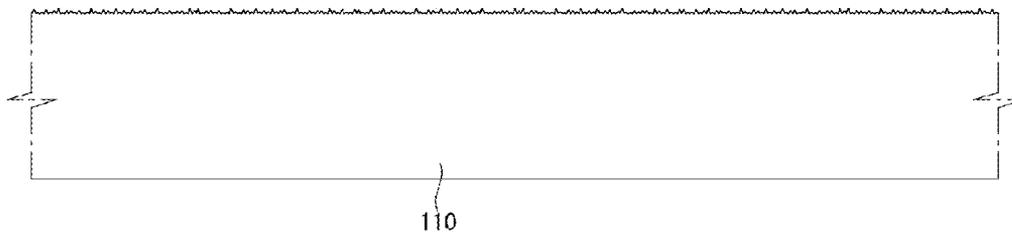


FIG. 12B

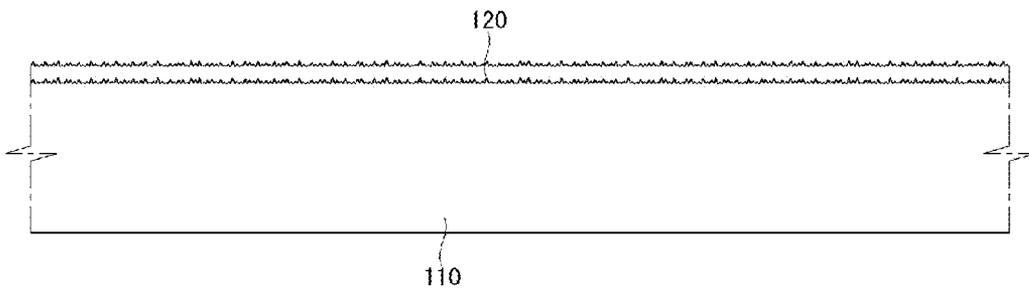


FIG. 12C

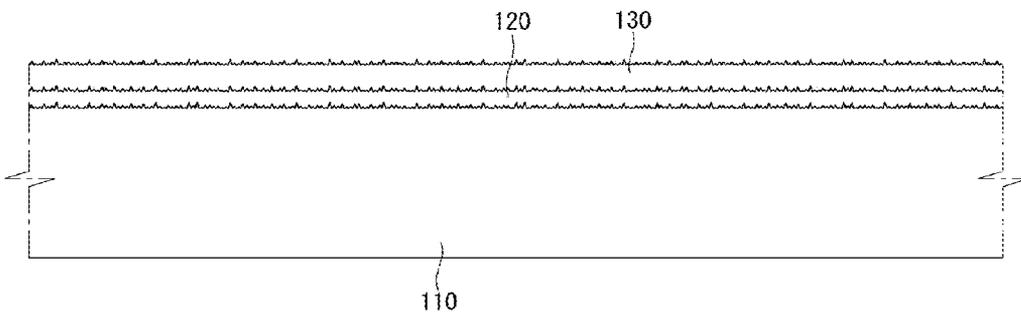


FIG. 12D

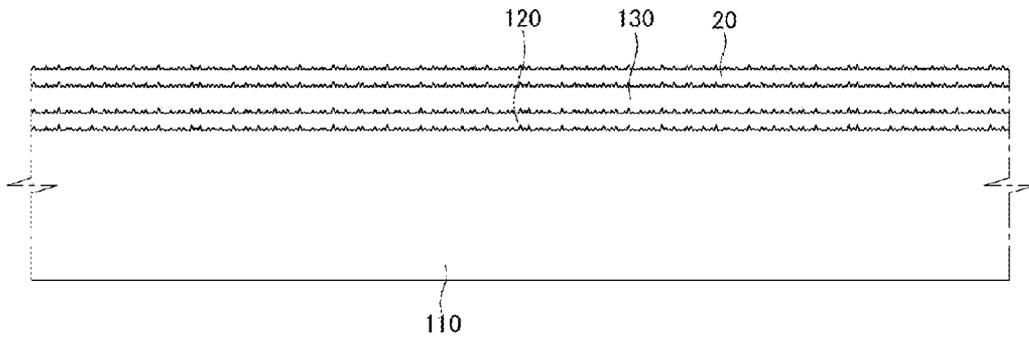


FIG. 12E

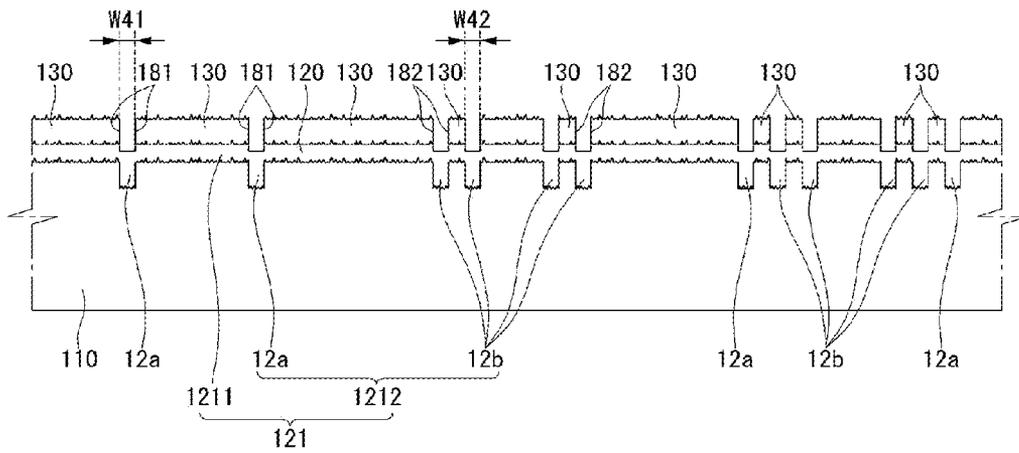


FIG. 12F

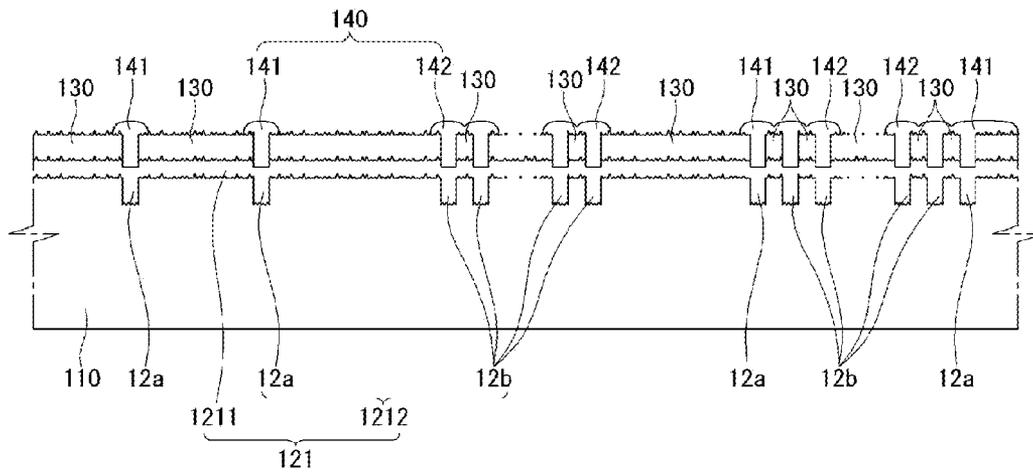


FIG. 12G

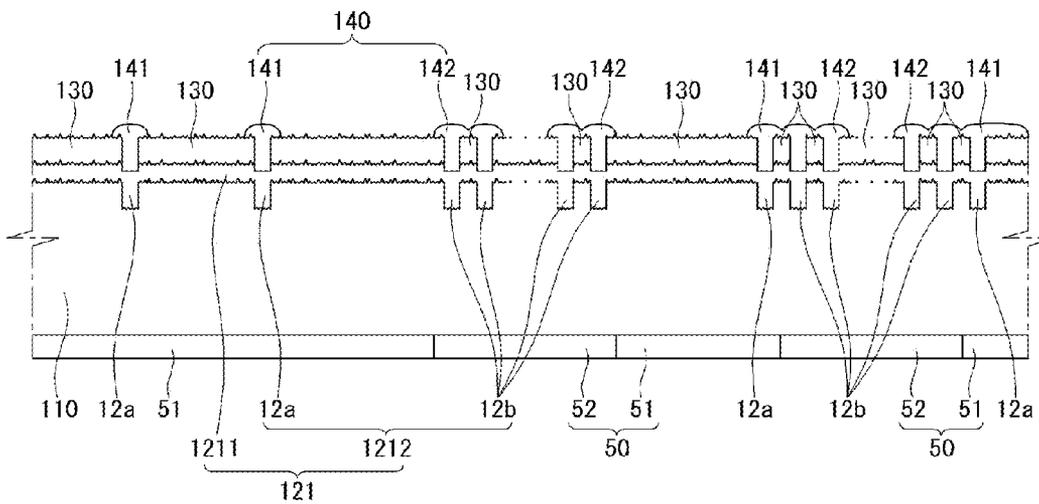


FIG. 13

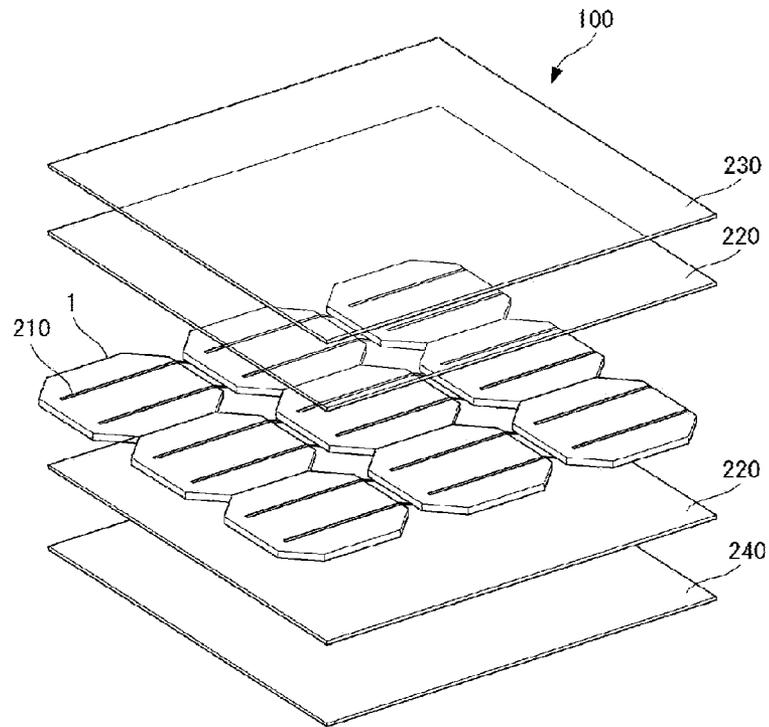


FIG. 14

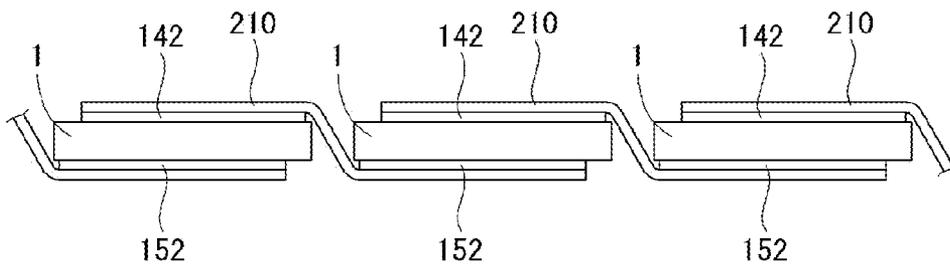


FIG. 15

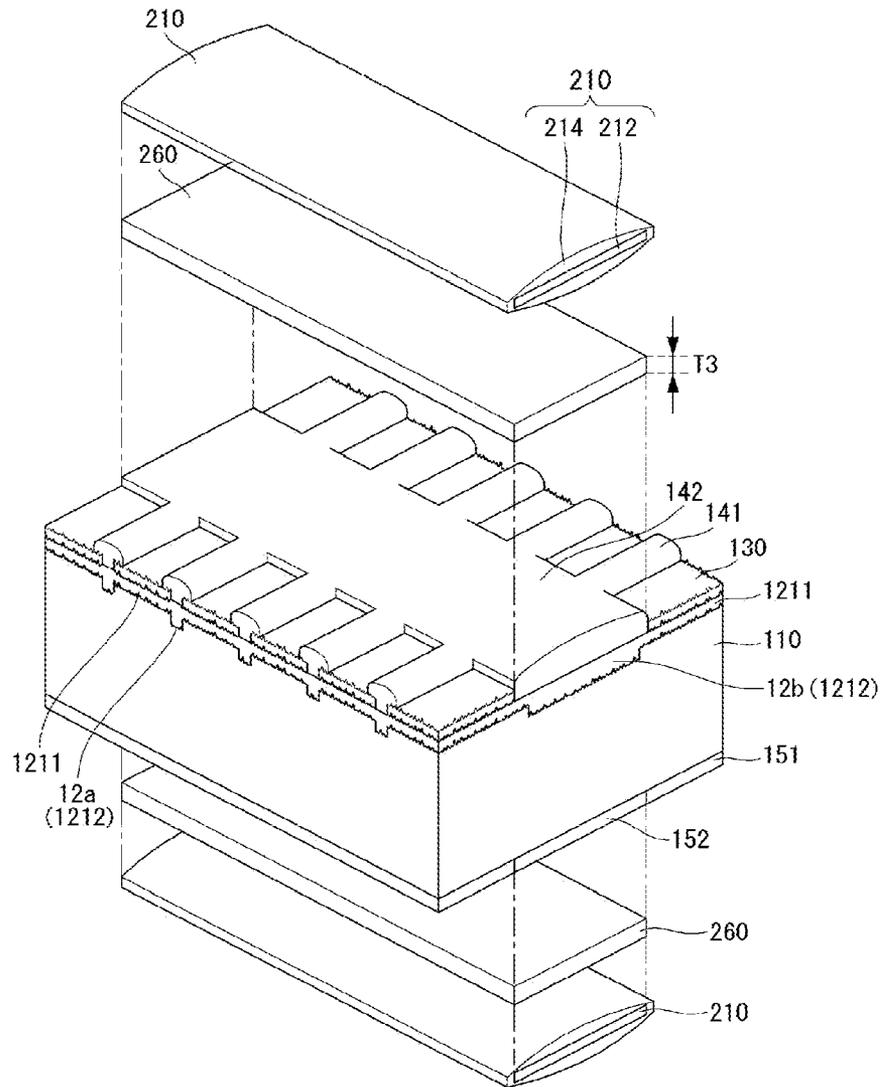


FIG. 16

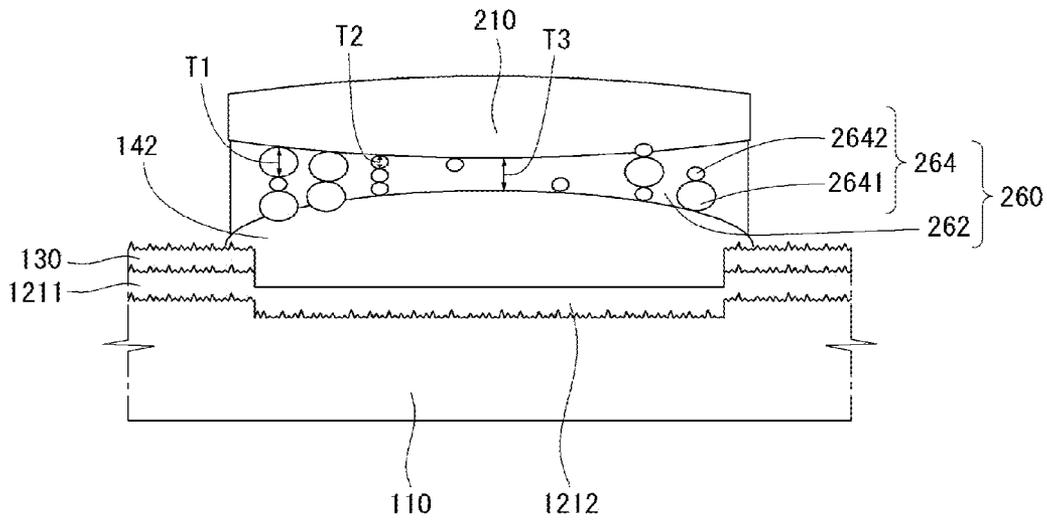


FIG. 17

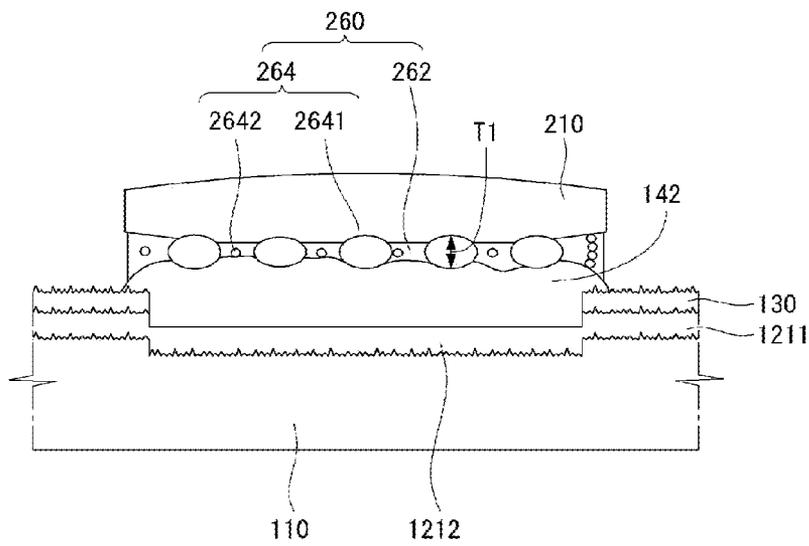


FIG. 18

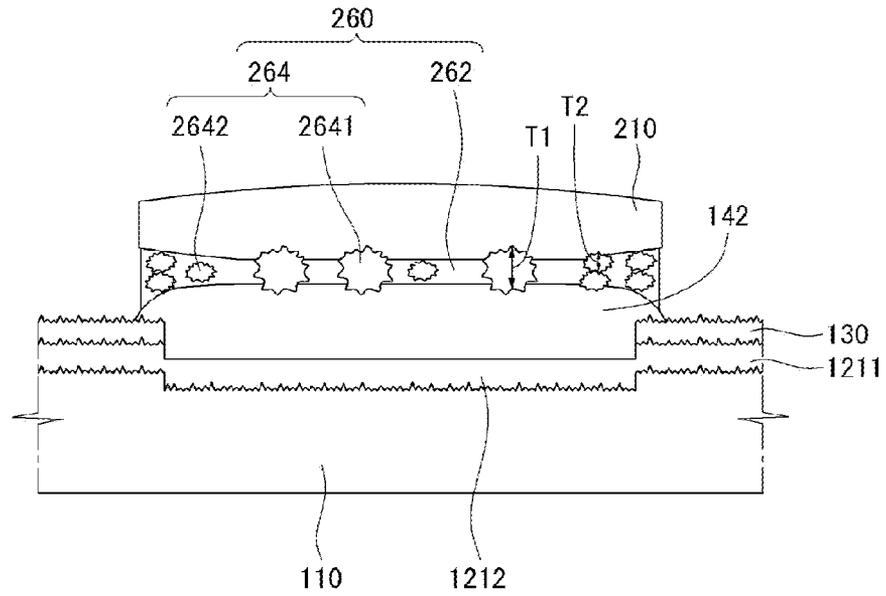
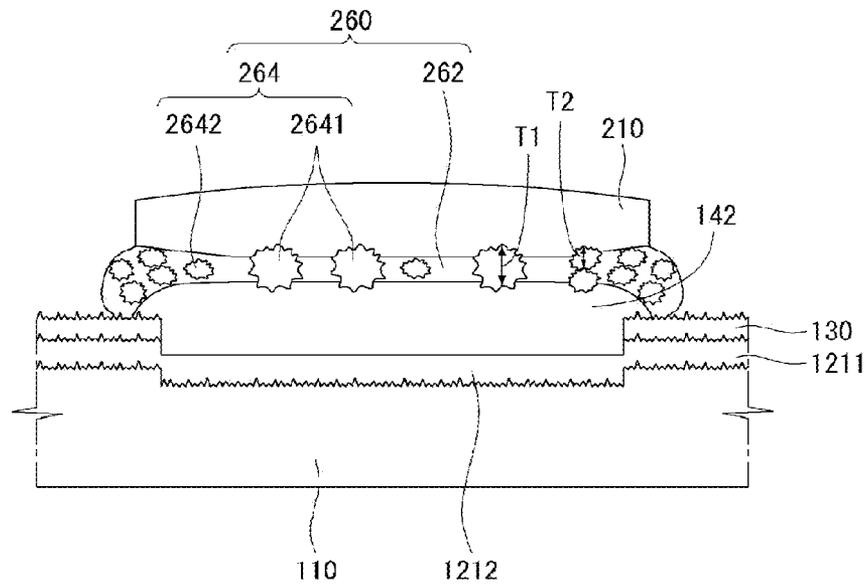


FIG. 19



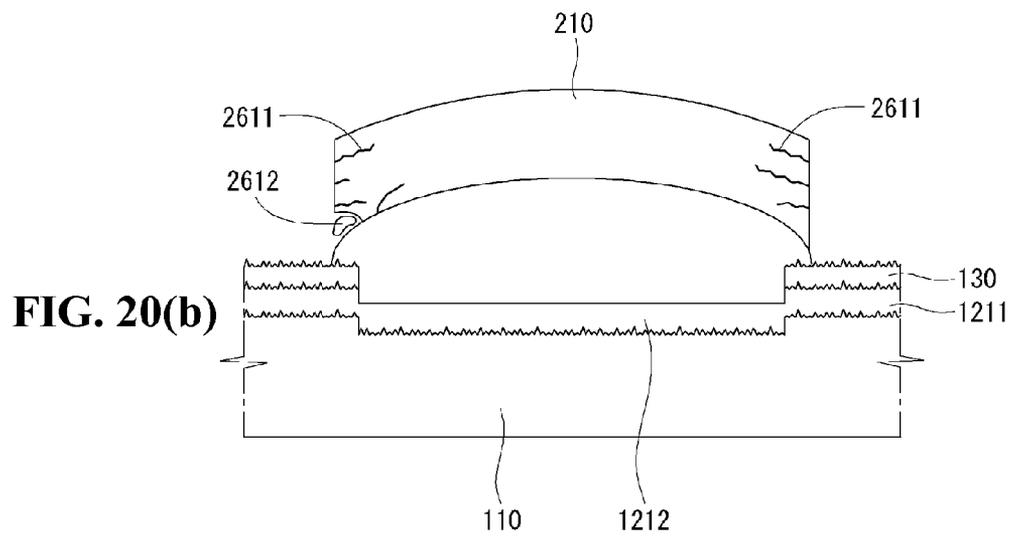
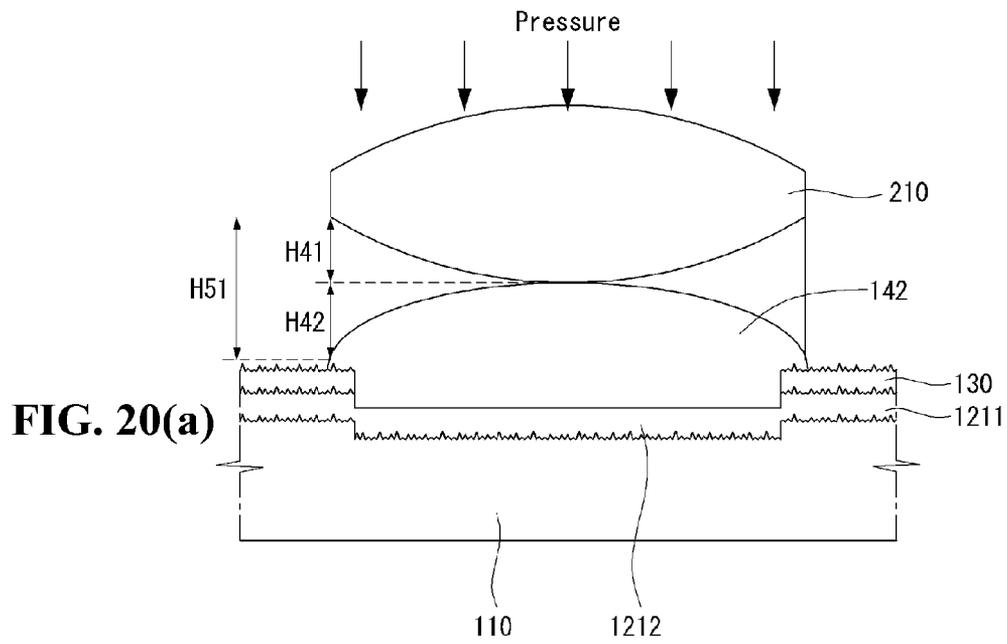


FIG. 21

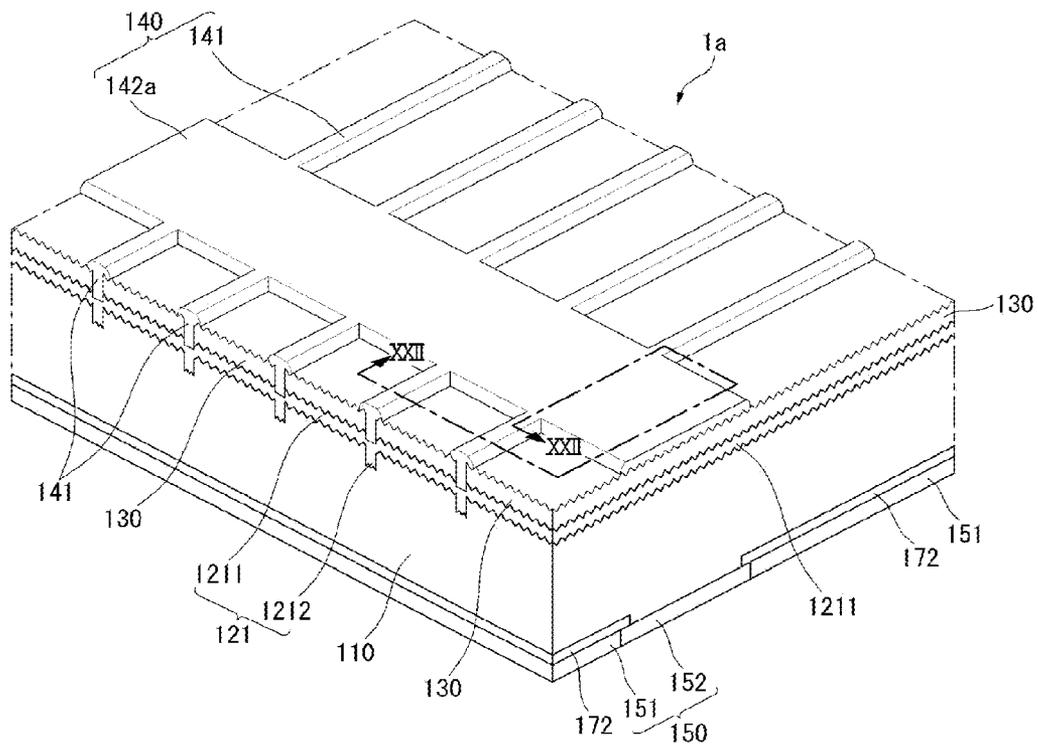


FIG. 22

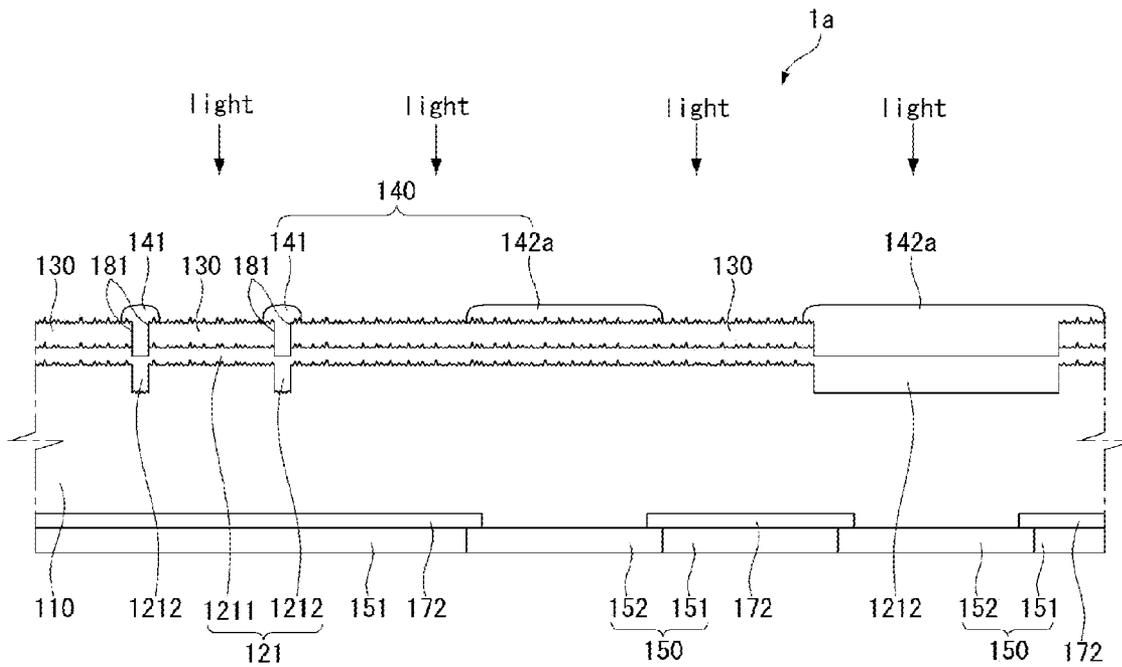
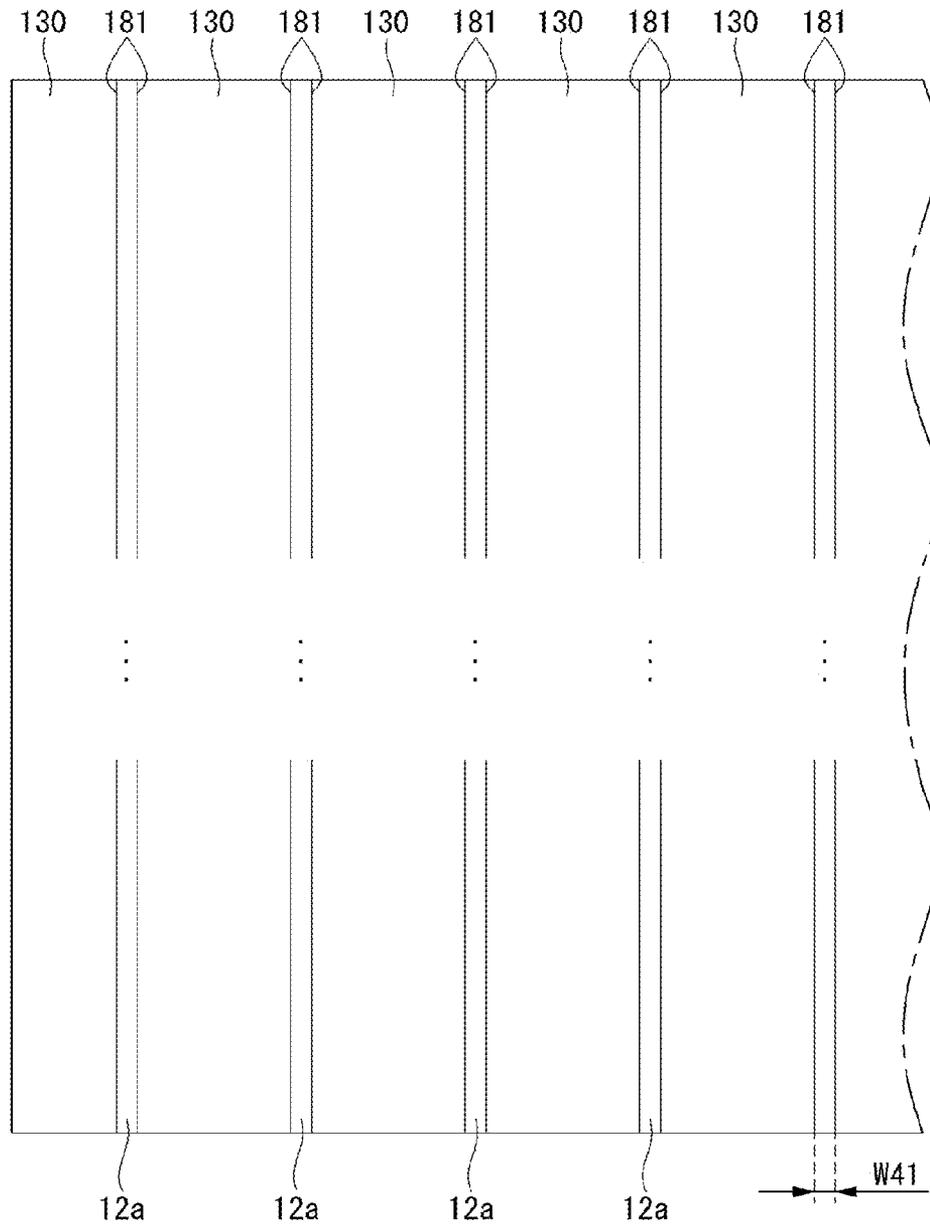


FIG. 23



SOLAR CELL MODULE

This application is a continuation of U.S. application Ser. No. 13/472,038 filed May 15, 2012, which claims priority to and benefit of Korean Patent Application No. 10-2012-0018330, filed in the Korean Intellectual Property Office on Feb. 23, 2012, the entire contents of which are incorporated herein by reference.

BACKGROUND

(a) Field of Disclosure

The present disclosure relates to a solar cell module.

(b) Description of the Related Art

As the existing energy resources, such as oil or coal, are expected to be exhausted, there is recently an increasing interest in alternative energy sources that will replace the existing energy resources, and thus a solar cell that generates electrical energy using solar power has been in the spotlight.

A common solar cell includes semiconductor regions, forming a p-n junction by different conductive types like a p type and an n type, and electrodes connected to the respective semiconductor regions having different conductive types.

When sunlight is incident on the solar cell, electrons and holes are generated from the semiconductor. Electrons generated from the p-n junction move toward the n type semiconductor region, and holes generated from the p-n junction move toward the p type semiconductor region. The moved electrons and holes are collected by the different electrodes connected to the p type semiconductor region and the n type semiconductor region, and electric power is obtained by connecting the electrodes using electric wires.

SUMMARY

A solar cell module according an aspect of present invention comprises a plurality of solar cells each comprising a substrate, an emitter region placed at the substrate, an anti-reflection region placed on the emitter region, first electrodes placed on the substrate, first bus bars placed on the substrate and connected to the first electrodes, second electrodes placed on the substrate, and second bus bars placed on the substrate and connected to the second electrodes; the anti-reflection region comprising a first opening region through which part of the emitter region is exposed and one or more second opening regions through which part of the emitter region is exposed, wherein the first electrode is connected to the exposed emitter region of the first opening region through the anti-reflection region by metal plating and the first bus bar is connected to the exposed emitter region of one or more second opening regions through the anti-reflection region by metal plating; and an interconnector to electrically connect the first bus bar and the first bus bar or the second bus bar of an adjacent solar cell of the plurality of solar cells.

A resistance value of the exposed emitter region of the first opening region may be greater than a resistance value of the exposed emitter region of the one or more second opening regions.

A conductive adhesion film may be placed between at least one of the first bus bar and the second bus bar and the interconnector, and may contain a plurality of conductive particles dispersed in resin to electrically connect at least one of the first bus bar and the second bus bar and the interconnector.

At least one of the plurality of conductive particles may have a thickness greater than or equal to a thickness of the conductive adhesion film. In another aspect, at least one of the plurality of conductive particles has a thickness smaller than a thickness of the conductive adhesion film.

At least one of the plurality of conductive particles may be embedded in at least one of the interconnector and the first bus bar or the second bus bar.

The conductive particle may be formed of a metal-coated resin particle comprising one or more kinds, selected from copper (Cu), silver (Ag), gold (Au), iron (Fe), nickel (Ni), lead (Pb), zinc (Zn), cobalt (Co), titanium (Ti), and magnesium (Mg), as ingredients.

The conductive particle may be formed of a metal particle made of one or more kinds, selected from copper (Cu), silver (Ag), gold (Au), iron (Fe), nickel (Ni), lead (Pb), zinc (Zn), cobalt (Co), titanium (Ti), and magnesium (Mg).

The metal particle may have a circle, an oval, or a radial shape. In another aspect, at least one of the conductive particles may have irregular or protruded portions.

The interconnector may be made of conductive metal.

The conductive metal may comprises a lead component of 1,000 ppm or less.

The interconnector may further comprise solder coated on a surface of the conductive metal.

At least one of the first bus bar and the second bus bar may have an uneven surface.

The conductive adhesion film may have the same width as at least one of the first bus bar and the second bus bar.

The conductive adhesion film may have a greater width than at least one of the first bus bar and the second bus bar.

The anti-reflection region may further comprise a plurality of grooves spaced apart from the plurality of second opening regions and have the anti-reflection region or the emitter region exposed therethrough.

Nickel silicide may be included in between the substrate and at least one of the first electrode and the first bus bar.

At least one of the first electrode and the first bus bar may be formed by the metal plating such that at least one curved surface shape is formed.

At least one of the first electrode and the first bus bar may comprise a first film placed on the substrate and made of nickel (Ni) and a second film placed on the first film and made of silver (Ag) or copper (Cu).

At least one of the first electrode and the first bus bar may further comprise a third film placed on the second film and made of silver (Ag) or tin (Sn) when the second film may be made of copper (Cu).

A first surface of at least one of the first bus bar and the second bus bar coming in contact with the conductive adhesion film may have a convex curved surface.

A height at a center of the conductive adhesion film may be smaller than a height at an edge of the conductive adhesion film.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a partial perspective view of an example of a solar cell according to an embodiment of the present invention;

FIG. 2 is a cross-sectional view of the solar cell of FIG. 1 taken along line II-II;

FIGS. 3(a) and 3(b) are respective diagrams showing enlarged parts of 'A' in FIG. 2;

FIGS. 4(a) and 4(b) are respective plan views of a first opening region or a second opening region;

FIGS. 5 and 6 are schematic plan views each showing part of the front electrode region of the solar cell and part of an emitter region placed under the front electrode region thereof according to the present embodiment;

FIGS. 7 and 8 are schematic plan views each showing a plurality of first and second opening regions formed in an anti-reflection region according to the present embodiment;

FIG. 9 is a schematic cross-sectional view showing part of front bus bars plated over second emitter parts exposed through the second opening regions according to the present embodiment;

FIGS. 10(a) to 10(c) are schematic cross-sectional views showing a process of forming the front bus bars by performing plating on the second emitter parts exposed through the second opening regions according to the present embodiment;

FIG. 11 is a partial cross-sectional view of another example of a solar cell according to an embodiment of the present invention;

FIGS. 12a to 12g are diagrams sequentially showing a method of manufacturing the solar cell shown in FIGS. 1 and 2;

FIG. 13 is a plan view of a solar cell module according to an embodiment of the present invention;

FIG. 14 is a schematic lateral view showing an example in which adjacent solar cells in FIG. 13 are coupled in series by an interconnector;

FIG. 15 is a schematic exploded perspective view of the solar cell module according to an embodiment of the present invention;

FIGS. 16 to 19 are cross-sectional views showing various examples in each of which the front bus bar and the interconnector are coupled using a conductive adhesion film in FIG. 13;

FIGS. 20(a) and 20(b) are cross-sectional views showing states in each of which the front bus bar and the interconnector are coupled according to a comparison example;

FIG. 21 is a partial perspective view of yet another example of a solar cell according to an embodiment of the present invention;

FIG. 22 is a cross-sectional view of the solar cell of FIG. 21 taken along line XXII-XXII; and

FIG. 23 is a schematic plan view of a plurality of first opening regions formed in an anti-reflection region in the solar cell of FIGS. 21 and 22.

DETAILED DESCRIPTION OF THE EMBODIMENTS

Hereinafter, some exemplary embodiments of the present invention are described in detail with reference to the accompanying drawings in order for those skilled in the art to be able to readily implement the invention. However, the present invention may be modified in various forms and are not limited to the following embodiments. In order to clarify a description of the embodiments of the present invention, parts not related to the description may be omitted, and the same reference numbers are used throughout the drawings to refer to the same or like part.

In the drawings, the thickness of each of layers and regions may be enlarged for better understanding and ease of description. When it is described that one part, such as a layer, a region, or a plate, is “over” the other part, it means not only that one part is placed “right on” the other part, but also that a third part is placed between one part and the other part. Meanwhile, when it is described that one part, such as

a layer, region, or plate, is “right on” the other part, it means that a third part does not exist between one part and the other part.

A solar cell and a solar cell module according to an embodiment of the present invention are described below with reference to the accompany drawings.

An example of a solar cell 1 according to an embodiment of the present invention is described in detail with reference to FIGS. 1 to 8.

Referring to FIGS. 1 and 2, the solar cell 1 according to the embodiment of the present invention includes a substrate 110, an emitter region 121 placed on the front surface (i.e., a first surface) side of the substrate 110 on which light is incident, an anti-reflection region 130 placed over the emitter region 121, a front electrode region 140 placed over the front surface of the substrate 110 and configured to include a plurality of front electrodes 141 (i.e., a plurality of first electrodes) and a plurality of front bus bars 142 (i.e., a plurality of first bus bars) connected to the plurality of front electrodes 141, back surface field regions 172 placed on the back surface (i.e., a second surface) side of the substrate 110 (i.e., an opposite surface to the front surface of the substrate 110), and back electrode regions 150 placed on the back surface field regions 172 and the back surface of the substrate 110 and configured to include a plurality of back electrodes 151 (i.e., second electrodes) and a plurality of back bus bars 152 (i.e., a plurality of second bus bars) connected to the back electrodes 151.

The substrate 110 is a semiconductor substrate formed to have a first conductive type (e.g., a p type conductive type) and made of semiconductor, such as silicon. The semiconductor is a crystalline semiconductor, such as polycrystalline silicon or single crystalline silicon.

When the substrate 110 is a p type conductive type, impurities of a group III element, such as boron (B), gallium (Ga), or indium (In), are doped into the substrate 110. However, the substrate 110 may be an n type conductive type and may be made of semiconductor materials other than silicon. When the substrate 110 has an n type conductive type, impurities of a group V element, such as phosphorus (P), arsenic (As), or antimony (Sb), are doped into the substrate 110.

As shown in FIGS. 1 to 3, the front surface of the substrate 110 is textured, thus having a textured surface (i.e., a concave-convex surface) having a plurality of convex parts 11 and a plurality of concave parts 12. Since the surface area of the substrate 110 is increased by the textured surface, an area on which light is incident is increased, but the amount of light reflected from the substrate 110 is reduced. Accordingly, the amount of light incident on the substrate 110 is increased.

As described above, the front surface of the substrate 110 is the concave-convex surface having the plurality of convex parts 11 and the plurality of concave parts 12. As shown in FIGS. 1 to 3, each of the emitter region 121 placed over the front surface of the substrate 110 and a surface of the anti-reflection region 130 placed over the emitter region 121 also have a concave-convex surface including a plurality of convex parts 21 and a plurality of concave parts 22.

The emitter region 121 is an impurity doping region into which impurities having a second conductive type (e.g., an n type conductive type) opposite to the conductive type of the substrate 110 have been doped and is placed on the front surface side of the substrate 110. Thus, the emitter region 121 and the first conductive type region of the substrate 110 form a p-n junction.

The emitter region **121** includes a first emitter part **1211** (i.e., a first impurity doping part) and a second emitter part **1212** (i.e., a second impurity doping part) having different impurity doping thicknesses and different surface resistance values.

In the present embodiment, an impurity doping thickness of the first emitter part **1211** is smaller than an impurity doping thickness (i.e., depth) of the second emitter part **1212**, and thus an impurity doping concentration of the first emitter part **1211** is also smaller than an impurity doping concentration of the second emitter part **1212**. Thus, a surface resistance value of the first emitter part **1211** is greater than a surface resistance value of the second emitter part **1212**. For example, the surface resistance value of the first emitter part **1211** may be about 80 Ω /sq. to 120 Ω /sq., and the surface resistance value of the second emitter part **1212** may be about 10 Ω /sq. to 50 Ω /sq.

Accordingly, the emitter region **121** of the present embodiment has a selective emitter structure including the first and the second emitter parts **1211** and **1212** having different surface resistance values and different impurity doping concentrations.

The p-n junction (i.e., the first junction) of the first emitter part **1211** and the substrate **110** [i.e., the first conductive type region of the substrate **110**] and the p-n junction (i.e., the second junction) of the second emitter part **1212** and the substrate **110** are placed at different heights. Accordingly, a thickness from the back surface of the substrate **110** to the first junction is greater than a thickness from the back surface of the substrate **110** to the second junction.

As shown in FIGS. **1** and **2**, the first emitter part **1211** of the emitter region **121** is placed under the anti-reflection region **130**. The second emitter part **1212** is placed under the plurality of front electrodes **141** and the plurality of front bus bars **142**. The second emitter part **1212** includes a second emitter part **12a** (i.e., the first part of the emitter region) for a plurality of electrodes which is the second emitter part **1212** placed under the plurality of front electrodes **141** and a plurality of second emitter parts **12b** (i.e., the second parts of the emitter region) for a plurality of bus bars which is the second emitter parts **1212** placed under the plurality of front bus bars **142**.

The width **W11** of the second emitter part **12a** for each electrode is identical with the width **W12** of the second emitter part **12b** for each bus bar. For example, each of the width **W11** of the second emitter part **12a** for each electrode and the width **W12** of the second emitter part **12b** for each bus bar may be about 5 μ m to 15 μ m.

As shown in FIGS. **5** and **6**, the second emitter part **12a** for each electrode lengthily extends in the same direction as the front electrode **141** along the front electrode **141** under the front electrode **141**. Thus, the second emitter part **12a** for one electrode exists in each of the front electrodes **141**.

The second emitter part **12b** for each bus bar extends in the same direction as the front bus bar **142** along the front bus bar **142** under the front bus bar **142**. The second emitter parts **12b** for the bus bars are spaced apart from one another. Accordingly, the first emitter part **1211** exists between the second emitter parts **12b** for adjacent bus bars.

As shown in FIG. **1**, the direction in which the plurality of front electrodes **141** extends and the direction in which the plurality of front bus bars **142** extends cross each other. Thus, the plurality of front electrodes **141** and the plurality of front bus bars **142** are interconnected at parts where the plurality of front electrodes **141** and the plurality of front bus bars **142** cross each other. Accordingly, the second emitter parts **12a** for the electrodes and the second emitter parts **12b**

for the bus bars, extending in the same direction as the plurality of front electrodes **141** and the plurality of front bus bars **142** under the plurality of front electrodes **141** and the plurality of front bus bars **142**, respectively, are interconnected at parts where the second emitter parts **12a** for the electrodes and the second emitter parts **12b** for the bus bars cross each other.

When the parts where the plurality of front electrodes **141** and the plurality of front bus bars **142** cross each other are excluded, the plurality of second emitter parts **1212** [i.e., the second emitter parts **12b** for the bus bars] spaced apart from one another exists under each of the front bus bars **142**. In the present embodiment, an interval **D11** between the second emitter parts **12b** for two adjacent bus bars may be 15 μ m to 30 μ m.

In the solar cell **1** of the present embodiment, as shown in FIGS. **1** and **2** and **5** and **7**, the interval **D11** between the second emitter parts **1212** [i.e., the second emitter parts **12b** for the bus bars] placed under each of the front bus bars **142** is regular.

In another embodiment, however, as shown in FIGS. **6** and **8**, the interval **D11** between the second emitter parts **1212** [i.e., the second emitter parts **12b** for the bus bars] placed under each of the front bus bars **142** is different.

For example, as shown in FIGS. **6** and **8**, the interval **D11** between the second emitter parts **12b** for the bus bars that are placed at a central part of a width **W3** where the plurality of second emitter parts **12b** for the bus bars corresponding to each of the front bus bars **142** are formed may be greater than the interval **D11** between the second emitter parts **12b** for the bus bars that are placed at edge parts of the width **W3** where the plurality of second emitter parts **12b** for the bus bars corresponding to each of the front bus bars **142** are formed.

In this case, the interval **D11** between the second emitter parts **12b** for the bus bars that are placed at the central part of the width **W3** where the plurality of second emitter parts **12b** for the bus bars corresponding to each of the front bus bars **142** are formed may be the same. The interval **D11** between the second emitter parts **12b** for the bus bars that are placed at the edge parts of the width **W3** where the plurality of second emitter parts **12b** for the bus bars corresponding to each of the front bus bars **142** are formed may be the same.

Here, the interval **D11** between the second emitter parts **12b** for the bus bars that are placed at the central part of the width **W3** where the plurality of second emitter parts **12b** for the bus bars corresponding to each of the front bus bars **142** are formed may be about 1.5 to 5 times the interval **D11** between the second emitter parts **12b** for the bus bars that are placed at the edge parts of the width **W3** where the plurality of second emitter parts **12b** for the bus bars corresponding to each of the front bus bars **142** are formed.

The present invention is, however, not limited to the above example. For example, the interval **D11** between the second emitter parts **12b** for two adjacent bus bars may be different irrespective of a position of the width **W3** where the plurality of second emitter parts **12b** for the bus bars are formed.

In the present embodiment, the number of second emitter parts **1212** [i.e., the second emitter parts **12b** for the bus bars] placed under each of the front bus bars **142** may be, for example, about 30 to 70 depending on the width of each of the second emitter parts **1212**, the interval **D11** between the second emitter parts **12b** for two adjacent bus bars, and the width of each of the second emitter parts **12b**.

Electrons, from among electrons and holes (i.e., electric charges generated by light incident on the substrate **110** by a built-in potential difference due to the p-n junction formed between the substrate **110** and the emitter region **121**), move toward an n type, and the holes move toward a p type. Accordingly, when the substrate **110** is a p type and the emitter region **121** is an n type, electrons move toward the emitter region **121**, and holes move toward the back surface of the substrate **110**.

The emitter region **121**, together with the substrate **110**, forms the p-n junction. Unlike in the above, when the substrate **110** has an n type conductive type, the emitter region **121** has a p type conductive type. In this case, electrons move toward the back surface of the substrate **110**, and holes move toward the emitter region **121**.

When the emitter region **121** has an n type conductive type, impurities of a group V element may be doped into the emitter region **121**. When the emitter region **121** has a p type conductive type, impurities of a group III element may be doped into the emitter region **121**.

When the first emitter part **1211** has a surface resistance value of about 80 Ω /sq. or higher to about 120 Ω /sq. or lower, the amount of light absorbed by the first emitter part **1211** is further reduced. Thus, the amount of light incident on the substrate **110** is increased, and the loss of electric charges due to impurities is further reduced.

Furthermore, if the second emitter part **1212** has a surface resistance value of about 10 Ω /sq. or higher to about 50 Ω /sq. or lower, the loss of electric charges due to resistance during the movement of electric charges is reduced because specific contact resistivity between the second emitter part **1212** and the front electrode region **140** is reduced.

Since the first emitter part **1211** of the emitter region **121** is placed under the anti-reflection region **130** as described above, the anti-reflection region **130** is placed over the first emitter part **1211** of the emitter region **121**. Accordingly, the first emitter part **1211** exists between the second emitter parts **12b** for two adjacent bus bars, from among the second emitter parts **12b** for the bus bars which are placed under each of the front bus bars **142**. Thus, the anti-reflection region **130** exists over the first emitter part **1211** placed between the second emitter part **12b** for adjacent bus bars.

The anti-reflection region **130** is composed of hydrogenated silicon nitrides (SiNx:H), hydrogenated silicon oxides (SiOx:H), hydrogenated silicon oxide nitrides (SiOxNy:H), or aluminum oxides (AlxOy).

The anti-reflection region **130** increases the efficiency of the solar cell **1** by reducing the reflectance of light incident on the solar cell **1** and increasing the selectivity of a specific wavelength region.

Furthermore, the anti-reflection region **130** plays a role of a passivation region that performs a passivation function of reducing the extinction of electric charges that have moved toward a surface of the substrate **110** owing to defects by changing defects, such as dangling bonds existing in the surface of the substrate **110** and peripheral parts thereof, into stable bonds through hydrogen (H) or oxygen (O) injected when the anti-reflection region **130** is formed. Thus, the efficiency of the solar cell **1** can be improved because the anti-reflection region **130** reduces the amount of electric charges lost in the surface of the substrate **110** and peripheral parts thereof owing to defects.

A top surface (i.e., a surface coming in contact with the front electrode region **140**) of the anti-reflection region **130**, as described above, includes the concave-convex surface having the plurality of first convex parts **21** and the plurality of second concave parts **22** owing to the textured surface

(i.e., the concave-convex surface) of the substrate **110** placed under the anti-reflection region **130**. Thus, the amount of light incident on the substrate **110** is increased.

Furthermore, the top surface of the anti-reflection region **130** partially comes in contact with the front electrode **141** and the front bus bar **142**.

The top surface of the anti-reflection region **130** coming in contact with the front electrode **141** and the front bus bar **142** includes a plurality of grooves **180** as shown in FIG. **3(a)**.

Each of the grooves **180** is placed in each of the convex parts **21** placed in the top surface of the anti-reflection region **130** that comes in contact with the front electrode region **140** and is formed by partially removing the anti-reflection region **130**. The groove **180** is depressed by a specific thickness or depth D1 from the top surface of the anti-reflection region **130** toward the bottom surface of the anti-reflection region **130** (i.e., a surface placed on the side opposite to the top surface of the anti-reflection region **130** and coming in contact with the emitter region **121**). In FIG. **3(a)**, the plurality of grooves **180** formed in the top surface of the anti-reflection region **130** is formed by partially removing only the anti-reflection region **130** and is placed within only the anti-reflection region **130**.

In another embodiment, however, as shown in FIG. **3(b)**, the plurality of grooves **180** formed in the anti-reflection region **130** coming in contact with the front electrode region **140** is formed by partially removing not only the anti-reflection region **130**, but also the emitter region [i.e., the first emitter part **1211**] under the anti-reflection region **130**.

Accordingly, the anti-reflection region **130** or the first emitter part **1211** of the emitter region **121** is exposed through the grooves **180**.

In FIG. **3(b)**, the depth D1 of each of the grooves **180** is greater than the depth D1 shown in FIG. **3(a)**.

The plurality of grooves **180** may be formed at desired positions by radiating a laser beam. The depth D1 of each of the grooves **180** may change depending on the intensity of the laser beam.

In the present embodiment, the depth D1 of each groove **180** may be a maximum value of depths that are measured in parallel to the side of the grooves **180** from a virtual line formed in each of the grooves **180** when the convex parts placed near the groove **180** are connected in a straight line.

In the present embodiment, when only the anti-reflection region **130** is exposed through each of the grooves **180** as shown in FIG. **3(a)**, each of the depth D1 and diameter of each of the grooves **180** may be about 300 nm to 10 μ m. When the emitter region **121** is exposed through the grooves **180** as shown in FIG. **3(b)**, each of the depth D1 and diameter of each of the grooves **180** may be about 70 nm to 120 nm.

The grooves **180** may have a stripe form in which the grooves **180** extend in the same direction along the second opening regions **182** in parallel to the second opening regions **182** or may be a circle or an oval.

In the present embodiment, the anti-reflection region **130** is illustrated to have a single film structure, but may have a multi-layered film structure, such as a dual film or may be omitted, if appropriate.

The front electrode region **140**, including the plurality of front electrodes **141** and the plurality of front bus bars **142**, is placed over the emitter region **121** and the anti-reflection region **130** and is connected to the second emitter parts **1212** of the emitter region **121**.

Accordingly, the anti-reflection region **130** includes a plurality of first opening regions **181** and a plurality of

second opening regions **182**. The plurality of first opening regions **181** is formed by partially removing the anti-reflection region **130** in order to connect each of the front electrodes **141** and each of the second emitter parts **12a** for the electrodes of the second emitter part **1212** and is formed to expose the second emitter parts **12a** for the electrodes, respectively, under the plurality of first opening regions **181**. The plurality of second opening regions **182** is formed by partially removing the anti-reflection region **130** in order to connect each of the front bus bars **142** and each of the second emitter parts **12b** for the bus bars of the second emitter part **1212** and is formed to expose the second emitter parts **12b** for the bus bars, respectively, under the plurality of second opening regions **182**.

The plurality of first and second opening regions **181** and **182** may be formed by radiating a laser beam to relevant positions of the anti-reflection region **130**.

Both sides of each of the second emitter parts **12a** and **12b** exposed through the first opening region **181** and the second opening region **182**, respectively, may have a plane as shown in FIG. 4(a) or may have a concave-convex surface (i.e., a non-plane) as shown in FIG. 4(b).

When both sides of the second emitter parts **12a** and **12b** exposed through the first opening region **181** and the second opening region **182**, respectively, have planes, a laser beam LB used may have a stripe form that has the same width as each of the first and the second opening regions **181** and **182**. When both sides of each of the second emitter parts **12a** and **12b** exposed through the first opening region **181** and the second opening region **182**, respectively, have planes, a laser beam LB used may have a spot form that has the same width as each of the first and the second opening regions **181** and **182**.

When both sides of each of the second emitter parts **12a** and **12b** exposed through the first opening region **181** and the second opening region **182**, respectively, have the concave-convex surfaces, the contact area of the front electrode **141** and the second emitter part **12a** and the contact area of the front bus bar **142** and the second emitter part **12b** are increased because the area of each of the second emitter parts **12a** and **12b** exposed through the first and the second opening regions **181** and **182** is increased. When the first and the second opening regions **181** and **182** are formed by using the laser beam LB having a stripe form, the time taken to form the first and the second opening regions **181** and **182** is reduced.

As shown in FIGS. 7 and 8, the width **W41** of the first second opening region **181** is identical with the width **W42** of the second opening region **182**. Each of the width **W41** of the first second opening region **181** and the width **W42** of the second opening region **182** may be about 5 μm to about 15 μm .

The plurality of first opening regions **181** is opening regions for forming the plurality of front electrodes **141** (i.e., opening regions for the front electrodes), and the plurality of second opening regions **182** is opening regions for forming the plurality of front bus bars **142** (i.e., opening regions for the front bus bars).

Each of the first opening regions **181** is the opening region for each of the front electrodes **141**. Thus, the number of first opening regions **181** formed in a formation region (hereinafter referred to as a 'front electrode formation region' or a 'first electrode formation region') AA where one front electrode **141** is formed in the anti-reflection region **130** is one. Accordingly, the number of first opening regions **181** is the same as the number of front electrodes **141**.

Unlike in the plurality of front electrodes **141**, in order to form one front bus bar **142** having a width of about 1 mm to 1.5 mm, the second opening regions **182** of about 30 to about 70 in number are required. Thus, the number of second opening regions **182** formed in a formation region (hereinafter referred to as a 'front bus bar formation region' or a 'first bus bar formation region') AB where one front bus bar **142** is formed in the anti-reflection region **130** is about 30 to about 70. Accordingly, the number of second opening regions **182** is much greater than the number of front bus bars **142**.

In order to form one front bus bar **142** as described above, when the plurality of second opening regions **182** spaced apart from one another are formed instead of forming one second opening region **182** having at least the same width as one front bus bar **142**, a total width of the plurality of second opening regions **182**, formed under one front bus bar **142**, to the width of the front bus bar formation region AB of the anti-reflection region **130** or the width **W3** where the plurality of second emitter parts **12b** for the bus bars corresponding to one front bus bar **142** are formed may be about 1:0.2 to 0.5.

As described above, the plurality of front electrodes **141** extend in parallel in a predetermined direction with them spaced apart from one another. Each of the front electrodes **141** is electrically and physically connected to each of the second emitter part **12a** for the electrodes of the second emitter part **1212**.

Each of the front electrodes **141** is placed over each of the second emitter parts **12a** for the electrodes and is also partially placed over an adjacent anti-reflection region **130**. Accordingly, as shown in FIGS. 5 and 6, the width **W21** of each of the front electrodes **141** placed over each of the second emitter parts **12a** for the electrodes is greater than the width **W11** of each of the second emitter parts **12a**. For example, the width **W21** of each of the front electrodes **141** may be 20 μm to 40 μm .

Thus, each of the front electrodes **141** is electrically and physically connected to the second emitter part **1212** [i.e., the second emitter part **12a** for the electrode].

The plurality of front electrodes **141** collects electric charges (e.g., electrons) that have moved to the second emitter parts **12a** for the electrodes of the second emitter part **1212** through the first emitter part **1211** of the emitter region **121**.

As described above, the number of first opening regions **181** through which the second emitter parts **12a** for the electrodes are exposed in order to form one front electrode **141** may be one, and the number of second opening regions **182** through which the second emitter parts **12b** for the bus bars are exposed in order to form one front bus bar **142** may be about 30 to 70.

In the present embodiment, a ratio of the total width of the plurality of second opening regions **182**, formed under one front bus bar **142**, to the width **W3** where the plurality of second emitter parts **12b** for the bus bars corresponding to one front bus bar **142** are formed may be about 1:0.2 to 0.5.

When the ratio of the total width of the plurality of second opening regions **182**, formed under one front bus bar **142**, to the width **W3** where the plurality of second emitter parts **12b** for the bus bars corresponding to one front bus bar **142** are formed is about 1:0.2 or higher, the front bus bar **142** with a desired width and desired conductivity can be obtained because one front bus bar **142** formed over the second emitter parts **12a** for the bus bars exposed through the plurality of second opening regions **182** is formed more stably.

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When the ratio of the total width of the plurality of second opening regions **182**, formed under one front bus bar **142**, to the width **W3** where the plurality of second emitter parts **12b** for the bus bars corresponding to one front bus bar **142** are formed is about 1:0.5 or lower, the time taken to form the plurality of second opening regions **182** can be further reduced and the area of the emitter region **121** exposed to heat in order to form the plurality of second opening regions **182** can be further reduced.

The plurality of front bus bars **142** is spaced apart from one another and is extended in parallel in a direction to cross the plurality of front electrodes **141**. Each of the front bus bars **142** is electrically and physically connected to the second emitter parts **12b** for the bus bars of the second emitter part **1212** that are exposed through the plurality of second opening regions **182**.

Furthermore, since the anti-reflection region **130** is placed between the second emitter parts **12b** for two adjacent bus bars, one front bus bar **142** is connected to not only the second emitter parts **1212** [i.e., the second emitter parts **12b** for the bus bars], but also the anti-reflection region **130**.

The first emitter part **1211** exists under the anti-reflection region **130** between the second emitter parts **12b** for two adjacent bus bars as described above. Accordingly, not only the second emitter parts **1212** [i.e., the second emitter parts **12b** for the bus bars], but also the first emitter part **1211** exist under the front bus bar **142**.

Like in each of the front electrodes **141**, the width **W22** of each of the front bus bars **142** placed over the substrate **110** is greater than the total width **W3** of the substrate **110** (i.e., the width where the plurality of second emitter parts for the bus bars is formed) in which the second emitter parts **12b** for the bus bars exiting under one front bus bar **142** are placed [i.e., in FIG. 5, a distance from the most lateral side of the second emitter part **12b** for the bus bar, placed at the top (i.e., the outermost corner), to the most lateral side of the second emitter part **12b** for the bus bar placed at the bottom (i.e., the outermost corner), from among the second emitter parts **12b** for the bus bars placed under one front bus bar **142**]. For example, the width **W22** of each of the front bus bars **142** may be 1 mm to 1.5 mm.

Consequently, each of the front bus bars **142** is electrically and physically connected to the second emitter parts **12a** for the electrodes of the second emitter part **1212** and the second emitter parts **12b** for the bus bars of the second emitter part **1212**.

The plurality of front bus bars **142** is placed in the same layer as the plurality of front electrodes **141**. As described above, the plurality of front bus bars **142** is electrically and physically connected to the relevant front electrodes **141** at points where the front bus bars **142** crosses the respective front electrodes **141**.

Accordingly, as shown in FIGS. 1 and 3, the plurality of front electrodes **141** has a stripe form in which the plurality of front electrodes **141** extends in one direction (i.e., a first direction), such as a horizontal or vertical direction. Furthermore, the plurality of front bus bars **142** has a stripe form in which the plurality of front bus bars **142** extends in the other direction (i.e., a second direction), such as a vertical or horizontal direction to cross the plurality of front electrodes **141**. Accordingly, the front electrode regions **140** are placed in the front surface of the substrate **110** in a lattice form.

The plurality of front bus bars **142** collects not only electric charges moved from the second emitter parts **1212** of the emitter region **121**, but also electric charges collected by the plurality of front electrodes **141** and moved and sends the collected electric charges in a relevant direction.

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Each of the front bus bars **142** has to collect electric charges collected by the plurality of front electrodes **141** to cross the front bus bar **142** and to move the electric charges in a desired direction. Accordingly, the width **W22** of each of the front bus bars **142** is greater than the width **W21** of each of the front electrodes **141**.

As described above, the emitter region **121** has the selective emitter structure including the first and the second emitter parts **1211** and **1212**. Thus, the first emitter part **1211** where the movement of electric charges to the front electrode region **140** is chiefly performed has a low impurity doping concentration, and the second emitter parts **1212** coming in contact with the front electrode region **140** has a high impurity concentration. Accordingly, the amount of electric charges that are moved from the second emitter parts **1212** to the front electrode region **140** is increased owing to an increase of conductivity due to an increased amount of electric charges, moved toward the front electrode region **140** through the first emitter parts **1211** of the emitter region **121**, and an increased impurity concentration. Consequently, the efficiency of the solar cell **1** can be significantly improved because the amount of electric charges collected by the front electrode region **140** in the emitter region **121** is increased.

In addition, the second emitter part **1212** that outputs electric charges by chiefly coming in contact with the front electrodes **141** and the front bus bars **142** of the front electrode region **140** has higher conductivity than the first emitter part **1211** and a lower surface resistance value than the first emitter part **1211** owing to the high impurity doping concentration. Consequently, the transmission efficiency of electric charges that are moved from the second emitter parts **1212** to the front electrode region **140** can be improved because specific contact resistivity between the second emitter parts **1212** and the front electrode region **140** is reduced.

Here, an area where the second emitter parts **12a** for the electrodes are formed (i.e., a high concentration impurity doping region) is reduced because the width **W11** of each of the second emitter parts **12a** for the electrodes of the second emitter part **1212** is smaller than the width **W21** of each of the front electrodes **141**. Furthermore, the width **W3** where the plurality of second emitter parts **12b** for the bus bars are formed is smaller than the width **W22** of each of the front bus bars **142**. In addition, each of the front bus bars **142** fully comes in contact with the second emitter part **1212**, but each of the front bus bars **142** is partially connected to the second emitter parts **12b** for the bus bars (i.e., a high concentration impurity doping region). Thus, an area where the high concentration impurity doping region [i.e., the second emitter parts **12b** for the bus bars] formed under each of the front bus bars **142** is formed can be reduced. Consequently, the efficiency of the solar cell **1** is improved because the high concentration impurity doping region **1212** is reduced in the emitter region **121** and thus the amount of electric charges lost by impurities is greatly reduced.

In order to fabricate one solar cell module by connecting the plurality of solar cells **1** in series or in parallel, an interconnector, such as a ribbon, is placed in the plurality of front bus bars **142**. In the present embodiment, a conductive adhesion film is placed between the plurality of front bus bars **142** and the interconnector, so that the plurality of front bus bars **142** and the interconnector are coupled electrically and physically. Since the plurality of front bus bars **142** is connected to an external device through the interconnector, electric charges (e.g., electrons) collected by the plurality of front bus bars **142** are outputted to the external device via the interconnector.

As described above, each of the front electrodes **141** and each of the front bus bars **142** are placed over not only the second emitter parts **12a** for the electrodes and the second emitter parts **12b** for the bus bars, but also the anti-reflection region **130**. Thus, the width of each of the front electrodes **141** and each of the front bus bars **142** is greater than the width of each of the opening regions **181** and **182**. Consequently, since the surface area and cross section of each of the front electrodes **141** and each of the front bus bars **142** are increased, the conductivity of each of the front electrodes **141** and each of the front bus bars **142** can be stably maintained, and thus electric charges can be stably moved. Furthermore, adhesive strength between each of the front bus bars **142** and the conductive adhesion film placed on the front bus bar **142** is further improved because the contact area with the front bus bar **142** comes in contact with the conductive adhesion film is increased.

As described above, the plurality of grooves **180** through which the anti-reflection region **130** or the first emitter parts **1211** of the emitter region **121** are exposed is formed in the parts of the anti-reflection region **130** where the anti-reflection region **130** comes in contact with the front electrode **141** and the front bus bar **142** of the front electrode region **140**. Accordingly, the front electrode **141** and the front bus bar **142** placed over the anti-reflection region **130** are also formed within the plurality of grooves **180**.

Consequently, an area where the front electrode **141** and the front bus bar **142** come in contact with the anti-reflection region **130** and the emitter region **121**, placed under the front electrode **141** and the front bus bar **142**, is increased. Thus, adhesive strength between the front electrodes **141**, and the anti-reflection region **130** and the emitter region **121** under the front electrodes **141** and adhesive strength between the front bus bars **142**, and the anti-reflection region **130** and the emitter region **121** under the front bus bars **142** are increased. Accordingly, physical bonding strength between the front electrodes **141**, and the anti-reflection region **130** and the emitter region **121** under the front electrodes **141** and physical bonding strength between the front bus bars **142**, and the anti-reflection region **130** and the emitter region **121** under the front bus bars **142** are improved.

In the present embodiment, the front electrode region **140** is formed using a plating method. To this end, after the plurality of first and second opening regions **181** and **182** through which the emitter regions **121** are exposed is formed in the anti-reflection region **130**, plating is performed on the emitter regions **121** exposed through the plurality of first and second opening regions **181** and **182** by using an electroplating method.

The characteristics of the front electrodes **141** and the front bus bars **142** when the front electrode region **140** is fabricated using the plating method are described below with reference to FIGS. **9** and **10**. In FIGS. **9** and **10**, a surface of the substrate **110** is illustrated to have a plane not a textured surface, for simplicity.

As shown in FIG. **9**, when the second opening regions **182** [or the plurality of first opening regions **181**] each having a predetermined width W_c are formed by removing the anti-reflection region **130** and plating is performed on the exposed second emitter parts **1212**, a plated thickness from the height of the top surface of the anti-reflection region **130** is H_f . As described above, since the plating is isotropic growth, a thickness plated on the anti-reflection region **130** in a horizontal direction from the end of the second opening region **182** [or the first opening region **181**] is also H_f . Accordingly, a top surface of the part plated on the second

emitter part **1212** exposed through the second opening region **182** [or the first opening region **181**] has a curved surface shape.

Accordingly, when the plating is performed, metal plating is performed in the second emitter part **1212** placed in each of the second opening regions **182** and each of the first opening regions **181** (not shown in FIG. **9**) is performed as shown in FIG. **10(a)**, so that desired metal is grown. Thus, as the front electrode region **140** including the plurality of front electrodes **141** and the plurality of front bus bars **142** starts being formed, the front electrodes **141** and the front bus bars **142** are gradually grown outside the first and the second opening regions **181** and **182**.

Here, the plating growth of metal for the front electrode regions **140**, as described above, is isotropic growth performed in the same speed not only in a vertical direction, but also in a horizontal direction. Thus, when the front electrodes **141** and the front bus bars **142** grown within the first and the second opening regions **181** and **182** are grown to the height of the top surface of the adjacent anti-reflection region **130** as shown in FIG. **10(b)**, metal is also grown even in the horizontal direction, so that the front electrodes **141** and the front bus bars **142** are also grown over the anti-reflection region **130** adjacent to the first and the opening regions **181** and **182**.

Accordingly, each of the top surface of each of the front electrodes **141** and the top surface of each of the front bus bars **142** has a curved surface shape.

In the present embodiment, the plurality of adjacent opening regions **182** is formed in order to form one front bus bar **142**. Accordingly, metal (i.e., part of each of the front bus bars **142**) grown in each of the two second opening regions **182** adjacent to each other, from among the plurality of second opening regions **182** formed to form the one front bus bar **142**, meet each other over the anti-reflection region **130** as shown in FIG. **10(c)**.

Consequently, although metal plating growth is performed within each of the second opening regions **182** spaced apart from each other, the interval D_{11} between the two adjacent second opening regions **182** is included within a range of the metal plating growth in the horizontal direction. Thus, the metals respectively grown around the two adjacent second opening regions **182** meet each other over the anti-reflection region **130** placed between the two second opening regions **182**, thereby forming the one front bus bar **142**.

Accordingly, the width of each of the front bus bars **142** finally formed [i.e., the width of a bottom surface of each of the front bus bars **142** coming in contact with the anti-reflection region **130** and the second emitter part **1212**] is greater than the width D_{21} of the front bus bar formation region AB.

Since the metal plating growth is isotropic growth as described above, a top surface [i.e., a surface of the front bus bar **142** placed on the opposite side to the bottom surface] of the metal (i.e., part of the front bus bar **142**) plated on the basis of each of the second opening regions **182** also has a curved surface shape. Metal plating is performed on the basis of each of the two adjacent second opening regions **182** and is overlapped with the anti-reflection region **130** placed between the two adjacent second opening regions **182**. Thus, the height of the top surface of the overlapping part of the metal grown by plating becomes higher than the height of the top surface of the metal part grown by plating on second emitter part **1212** exposed through the second opening region **182**.

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Accordingly, the top surface [i.e., the surface of the front bus bar **142** placed on the opposite side to the bottom surface] of each of the front bus bars **142**, formed on the anti-reflection region **130** and on the second emitter part **1212** that are exposed through the second opening region **182** has a curved surface shape including the concave-convex surface having the plurality of convex parts and the plurality of concave parts. As described above, the height of the top surface of the front bus bar **142** placed on the second emitter part **1212** exposed through the second opening region **182** is higher than the height of the front bus bar **142** placed on the anti-reflection region **130**.

Accordingly, a contact area where each of the front bus bars **142** comes in contact with the interconnector is increased because the surface roughness of the top surface of each of the front bus bars **142** is increased. Thus, the amount of electric charges moving from the front bus bars **142** to the interconnector is increased.

As shown in FIGS. **6** and **8**, when the interval **D11** between the second emitter parts **12b** for the bus bars placed under each of the front bus bars **142** is different according to a position, the overlapping area of a part grown by plating on the second emitter part **12b** for an adjacent bus bar at an edge part is more increased than the overlapping area of a part grown by plating on the second emitter part **12b** for an adjacent bus bar in the central part of each of the front bus bars **142**. Accordingly, a difference in the height between the central part and the edge part of each of the front bus bars **142** is reduced, and thus the flatness of the top surface of each of the front bus bars **142** (i.e., the concave-convex surface including the plurality of convex parts and the plurality of concave parts) is further increased. Consequently, an adhesion operation with the conductive adhesion film placed over each of the front bus bars **142** is facilitated, and adhesive strength is increased.

Each of the front electrodes **141** not having the plurality of convex parts and the plurality of concave parts has a smooth curved surface shape because it is formed using one first opening region **181**.

In FIG. **9**, the total width W_f of the plated front bus bar **142** is $W_c + 2H_f$. Since the plated metal [e.g., silver (Ag)] has specific line resistivity of about $2.2 \mu\Omega\text{cm}$, it can be seen that the specific line resistivity of the plated metal is about $\frac{1}{3}$ of specific line resistivity (i.e., about $6.7 \mu\Omega\text{cm}$) of the front bus bar made of silver (Ag) paste. The plated material has specific contact resistivity of about $1 \text{ m}\Omega\text{cm}$. It can also be seen that the specific contact resistivity of the plated material is about $\frac{1}{3}$ of specific contact resistivity (i.e., about $3 \text{ m}\Omega\text{cm}$) when silver (Ag) paste is used.

As described above, each of the specific line resistivity value and the specific contact resistivity value of the front bus bar **142** fabricated using plating is about $\frac{1}{3}$ of each of the specific line resistivity value and the specific contact resistivity value of the front bus bar fabricated using silver (Ag) paste. If the front bus bar **142** fabricated using the plating method and the front bus bar **142** fabricated using silver (Ag) paste have the same cross section, it can be seen that the operating characteristic (e.g., contact characteristic or conductivity) of the front bus bar fabricated using plating is about 3 times the operating characteristic of the front bus bar fabricated using silver (Ag) paste.

In FIG. **9**, When W_c is $10 \mu\text{m}$ and H_f is $10 \mu\text{m}$, a cross section A of part of the front bus bar **142** grown by plating in one second opening region **182** is about $257 \mu\text{m}^2$.

A cross section A_1 of one front bus bar **142** having the same line resistance as the front bus bar **142** fabricated using silver (Ag) paste may be calculated on the basis of an

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equation; $R (\text{line resistance}) = [\rho (\text{specific line resistivity}) \times I (\text{length})] / A_1 (\text{cross section})$. In the equation, a factor for the length I is omitted because the front bus bar fabricated using silver (Ag) paste has the same length I as the front bus bar **142** fabricated using plating.

Assuming that line resistance of the front bus bar fabricated using silver (Ag) paste is R_{paste} , $R_{\text{paste}} = 6.7 / 37500 = 1.786 \times 10^{-4} \Omega$ because the specific line resistivity is $6.7 \mu\Omega\text{cm}$ and the cross section is $37,500 \mu\text{m}^2$ as described above.

Accordingly, when line resistance R_{plating} of the front bus bar fabricated using plating is identical with the line resistance R_{paste} of the front bus bar fabricated using silver (Ag) paste, the cross section A_1 is calculated according to the following equation. Here, the front bus bar **142** fabricated using plating has specific line resistivity of $2.2 \mu\Omega\text{cm}$ as described above.

In ($R_{\text{plating}} = \rho / A_1$), the cross section A_1 is about $12,313 \mu\text{m}^2$ because $1.786 \times 10^{-4} \Omega = 2.2 / A_1$.

Accordingly, when the cross section A_1 is divided by the cross section A of the part grown by plating in one opening region **182**, the number of second opening regions **182** formed in the anti-reflection region **130** in order to obtain the cross section A_1 is calculated, and thus the number of second opening regions **182** each having a width of about $10 \mu\text{m}$ may be about 48.

In other words, in order to form one front bus bar **142** having a width of about 1.5 mm , about 48 opening regions **182** each having a width of about $10 \mu\text{m}$ are formed instead of forming one second opening region having a width of about 1.5 mm in the anti-reflection region **130**, and the front bus bar **142** is formed by plating within the second opening region **182**. In this case, the width of each of the front bus bars **142** formed on the plurality of second opening regions **182** is about 1.5 mm because the plating of the front bus bars **142** is isotropically grown not only over the second opening regions **182**, but also in the left and right directions as described above.

It can be seen that about 30 to 70 second opening regions **182** each having a width of about $5 \mu\text{m}$ to $15 \mu\text{m}$ are necessary to form one front bus bar **142** having a width of about 1 mm to 1.5 mm over the emitter region **121**, exposed through the plurality of second opening regions **182**, by using the plating method. Here, an interval between two adjacent second opening regions **182** may be about $15 \mu\text{m}$ to $30 \mu\text{m}$. The number of second opening regions **182** is changed according to the width of the second opening region **182** and the interval between the two adjacent second opening regions **182**.

When the interval between the two adjacent second opening regions **182** is about $15 \mu\text{m}$ or higher, the loss of electric charges due to the second emitter parts **12b** for the bus bars of the second emitter part **1212** is stably reduced because an area where the second emitter part **12b** (i.e., a high concentration impurity doping part) is formed is reduced. When the interval between the two adjacent second opening regions **182** is about $30 \mu\text{m}$ or higher, one front bus bar **142** having stable conductivity is formed on the plurality of second opening regions **182** because the front bus bars **142** grown in adjacent second opening regions **182**, respectively, come in contact with the adjacent second opening regions **182** more stably.

As described above, in order to form each of the front bus bars **142**, the anti-reflection region **130** of a part where one front bus bar **142** will be placed is removed partially or selectively, instead of removing the entire anti-reflection region **130** of a part where one front bus bar **142** will be

placed by using a laser in order to form each of the front bus bars **142**. Accordingly, the area of the anti-reflection region **130** to which the laser beam is radiated is reduced.

Accordingly, there are advantages in that the time taken to fabricate the solar cell **1** and a change in the characteristic of the solar cell **1** are reduced because the time taken to radiate a laser beam and a phenomenon in which the emitter region **121** or the substrate **110** is deteriorated by heat applied by the laser beam are reduced.

In the present embodiment, when the number of second opening regions **182** for one front bus bar **142** is 30 or greater, the front bus bars **142** having a more stable conductivity and surface area are formed. When the number of second opening regions **182** for one front bus bar **142** is 70 or smaller, an unnecessary waste of time and the radiation area of a laser are reduced.

Furthermore, the width of each of the first and the second opening regions **181** and **182** is more reduced than that when etch paste or an additional mask is used because a desired part of the anti-reflection region **130** is removed by using a laser beam directly radiated over the anti-reflection region **130**, instead of using an operation of removing the anti-reflection region **130** using the etch paste or mask.

Accordingly, an area where the plurality of front electrodes **141** is formed is reduced because an area where the second emitter part **1212** (i.e., a high concentration impurity doping part) is reduced and the width of the front electrode **141** is reduced.

In a solar cell **1** according to an alternative embodiment, as shown in FIG. **11**, the number of second opening regions **182** through which the second emitter part **12b** for the bus bar of the second emitter part **1212** is exposed in order to form one front bus bar **182** may be one.

In this case, since a contact area where each of the front bus bars **142** comes in contact with the second emitter part **12b** for the bus bar of the second emitter part **1212** is increased, adhesive strength between the front bus bar **142** and the second emitter part **1212** is increased.

In this case, as in each of the front electrodes **141**, one front bus bar **142** is made of material grown by plating in one opening regions **182** because only the second opening region **182** is necessary for the front bus bar **142**. Accordingly, a top surface of the front bus bar **142** formed in the second opening region **182** has a curved surface shape like the top surface of each of the front electrodes **141**, and the top surface of the front bus bar **142** has smaller roughness than the top surface of the front bus bar **142** formed through the plurality of second opening regions **182**. Consequently, the flatness of the top surface of the front bus bar **142** is greater than the flatness of the top surface of the front bus bar **142** formed through the plurality of second opening regions **182**.

In the present embodiment, the plurality of grooves **180** is not for a contact between the front electrode region **140** and the second emitter part **1212** of the emitter region **121**, but it functions to enhance adhesive strength between the front electrode region **140** and elements placed under front electrode region **140**. Accordingly, the depth D1 of each of the grooves **180** is not greater than the depth D2 of each of the first and the second opening regions **181** and **182**, and the depths D1 and D2 of the grooves **180** and the opening regions **181** and **182** are varied depending on the intensity of a laser beam (i.e., the magnitude of a wavelength). Accordingly, the intensity of a laser beam radiated to form the plurality of first and second opening regions **181** and **182** may be different from the intensity of a laser beam radiated to form the plurality of grooves **180**, and the intensity of the laser beam radiated to form the plurality of first and second

opening regions **181** and **182** may be greater than the intensity of the laser beam radiated to form the plurality of grooves **180**.

In the present embodiment, the wavelength of the laser beam used to form each of the plurality of first and second opening regions **181** and **182** and the plurality of grooves **180** may be about 350 nm to 1100 nm. For example, the laser beam used to form the plurality of first and second opening regions **181** and **182** may have a wavelength of 532 nm. The laser beam used to form the plurality of grooves **180** may have a wavelength of about 1100 nm. Furthermore, power of the laser beam for each of the first and the second opening regions **181** and **182** and the grooves **180** may be about 5 W to 20 W. The power, intensity (or wavelength), or radiation time of the laser beam may be determined depending on material or thickness of the anti-reflection region **130**.

An electroplating method or a Light-Induced Plating (LIP) may be used as the plating method.

The plurality of front electrodes **141** and the plurality of front bus bars **142** have the same film structure and material because the front electrodes **141** and the front bus bars **142** are formed at the same time using the same plating process. Furthermore, since the front electrode region **140** is formed by plating, the density of the front electrode region **140** is much greater than the density of a front electrode region fabricated using a screen-printing method, such as silver (Ag) paste. Accordingly, the conductivity of the front electrode region **140** can be significantly improved.

The front electrode region **140** including the plurality of front electrodes **141** and the plurality of front bus bars **142** has been illustrated to have a single film structure made of material, such as silver (Ag). In an alternative embodiment, the front electrode region **140** may have a multi-film structure, such as a dual film or a triple film.

When the front electrode region **140** is a single film made of silver (Ag), the front electrode region **140** may have specific line resistivity of 1.6 $\mu\Omega\text{cm}$ to 2.5 $\mu\Omega\text{cm}$. In this case, the specific line resistivity of the front electrode region **140** is much smaller than the specific line resistivity (i.e., about 6.7 $\mu\Omega\text{cm}$) of the front electrode region **140** made of silver (Ag) paste using a screen-printing method.

When the front electrode region **140** has a dual film structure, a lower film (i.e., a first film) coming in contact with the emitter region **121** (i.e. the second conductive type region of the substrate **110**) may be made of nickel (Ni), and an upper film (i.e., a second film) placed on the lower film may be made of silver (Ag). When the front electrode region **140** has a triple film structure, a lower film (i.e., a first film) coming in contact with the emitter region **121** may be made of nickel (Ni), a middle film (i.e., a second film) placed on the lower film may be made of copper (Cu), and an upper film (i.e., a third film) placed on the middle film may be made of silver (Ag) or tin (Sn). When the front electrode region **140** is the dual film, the lower film may have a thickness of about 0.5 μm to about 1 μm and the upper film may have a thickness of about 5 μm to about 10 μm . When the front electrode region **140** is the triple film, each of the lower film and the upper film may have a thickness of about 0.5 μm to about 1 μm and the middle film may have a thickness of about 5 μm to about 10 μm .

Here, the lower film of each of the front electrodes **141** and each of the front bus bars **142** functions to improve a contact characteristic by reducing specific contact resistivity with the second emitter part **1212** coming in contact with the lower film and functions as a seed layer for plating. The middle film of each of the front electrodes **141** and each of the front bus bars **142** is for reducing costs and may be made

of material having a low cost and excellent conductivity, such as copper (Cu). When the middle film is made of copper (Cu), the lower film placed under the middle film functions to prevent copper (Cu), having excellent bonding strength with silicon (Si), from functioning as impurities that penetrate into (or are absorbed by) the second emitter part **1212** made of silicon (Si) and thus hinder the movement of electric charges.

Furthermore, the upper film functions to prevent a film, placed under the upper film (e.g., the lower film or the middle film), from being oxidized and improve adhesive strength with a conductive adhesion film placed over the upper film.

When each of the front electrodes **141** and the front bus bars **142** is formed of the dual film or the triple film and the lower film is made of nickel (Ni) as described above, nickel silicide exists between the lower film and the emitter region **1212** owing to bond of nickel (Ni) and the emitter region **1212** (i.e., silicon (Si) forming the second conductive type region of the substrate **110**).

Meanwhile, when the front electrodes **141** and the front bus bars **142** are made of silver (Ag) paste including glass frit by using a screen-printing method, the glass frit penetrates the anti-reflection region **130** and thus comes in contact with the emitter region **1212**. Accordingly, at least one of components of the glass frit (e.g., at least one of material based on lead (Pb) such as PbO, material based on bismuth (Bi) such as Bi₂O₃, material based on aluminum (Al) such as Al₂O₃, material based on boron (B) such as B₂O₃, material based on tin (Sn) such as SnO, material based on zinc (Zn) such as ZnO, material based on titanium (Ti) such as TiO, and material based on phosphorus (P) such as P₂O₅) is detected in a part where the front electrode **141** and the front bus bar **142** come in contact with the emitter region **1212**.

In the present embodiment, however, the components of the glass frit are not detected between the front electrode **141** and the front bus bar **142**, and the substrate **110** [i.e., the emitter region **121**] because the front electrode **141** and the front bus bar **142** are formed by plating. When the front electrode region **140** has the multi-layered film as described above, the multi-layered film having a desired thickness sequentially from the lower film to the upper film is formed using the plating method.

In FIG. 1, the number of front electrodes **141**, the number of front bus bars **142**, and the number of second emitter parts **1212** placed in the substrate **110** are only illustrative and may be changed according to circumstances.

The back surface field region **172** is an impurity region where impurities having the same conductive type as the substrate **110** are doped at a higher concentration than the impurity region of the substrate **110** and may be a p+ region.

A potential barrier is formed owing to a difference in the impurity concentration between the first conductive type region of the substrate **110** and the back surface field region **172**, so that the potential barrier hinders holes from moving toward the back surface field region **172**, but facilitates the movement of the holes toward the back surface field region **172**. Accordingly, the amount of electric charges lost by a recombination of electrons and holes in the back surface of the substrate **110** and adjacent parts thereof is reduced, and the movement of desired electric charges (e.g., holes) is facilitated. Accordingly, the amount of electric charges moving toward the back electrode regions **150** is increased.

The back electrode region **150** includes the plurality of back electrodes **151** and the plurality of back bus bars **152** connected to the back electrodes **151**.

The back electrode **151** comes in contact with the back surface field region **172** placed in the back surface of the substrate **110**. The back electrodes **151** are substantially placed in the entire back surface of the substrate **110** other than the edges of the back surface of the substrate **110** and parts where the back bus bars **152** are placed.

The back electrode **151** includes conductive material, such as aluminum (Al) or silver (Ag).

The back electrode **151** collects electric charges (e.g., holes) moved toward the back surface field region **172**.

Specific contact resistivity between the substrate **110** (i.e., the back surface field region **172**) and the back electrode **151** is reduced because the back electrode **151** comes in contact with the back surface field region **172** having a higher impurity concentration than the substrate **110**. Accordingly, the transmission efficiency of electric charges from the substrate **110** to the back electrode **151** is improved.

The plurality of back bus bars **152** is placed in the back surface of the substrate **110** where the back electrodes **151** are not placed and is connected to adjacent back electrodes **151**.

Furthermore, the plurality of back bus bars **152** faces the respective front bus bars **142** on the basis of the substrate **110**.

The plurality of back bus bars **152**, likes the plurality of front bus bars **142**, collects electric charges transferred from the back electrodes **151**.

Like the plurality of front bus bars **142**, the interconnector is placed on the plurality of back bus bars **152**, and the plurality of back bus bars **152** is connected to an external device through the interconnector. Accordingly, electric charges (e.g., holes) collected by the plurality of back bus bars **152** are outputted to the external device. In this case, the conductive adhesion film is placed between the plurality of back bus bars **152** and the interconnector, thus electrically and physically coupling the plurality of back bus bars **152** and the interconnector.

The plurality of back bus bars **152** may be made of material having better conductivity than the back electrodes **151**, and it includes at least one conductive material, such as silver (Ag). Accordingly, the back electrodes **151** and the back bus bars **152** may be made of different materials.

The back electrodes **151** may be formed by a screen-printing method using paste including aluminum (Al) or silver (Ag), and the back bus bars **152** may also be formed by a screen-printing method using paste including silver (Ag).

Furthermore, the back electrodes **151** and the back bus bars **152** may also be formed using a plating method like the front electrodes **141** and the front bus bars **142**. In this case, like the front electrode region **140**, the back electrodes **151** and the back bus bars **152** are formed at the same time using the same plating process, and thus the back electrodes **151** and the back bus bars **152** may be made of the same material. In addition, the back electrodes **151** and the back bus bars **152** may be formed simultaneously with the front electrodes **141** and the front bus bars **142** using a plating process for the front electrodes **141** and the front bus bars **142**. In this case, the back electrode region **150** is made of the same material as the front electrode region **140**. Furthermore, the back electrode region **150** may have not only a single film, but also a multi-film, such as a dual film or a triple film.

In the case in which the back electrodes **151** and the back bus bars **152** are formed by the plating method and the back electrodes **151** and the back bus bars **152** have a dual film or a triple film as described above, when the back surface field region **172** (i.e., a lower film coming in contact with the part

of the substrate **110** into which impurities of the first conductive type have been doped at a high concentration) is made of nickel (Ni), nickel silicide exists between the lower film and the back surface field region **172** owing to a combination of nickel (Ni) and silicon (Si) in the back surface field region **172**.

Furthermore, a component of glass frit (e.g., at least one of material based on lead (Pb) such as PbO, material based on bismuth (Bi) such as Bi₂O₃, material based on aluminum (Al) such as Al₂O₃, material based on boron (B) such as B₂O₃, material based on tin (Sn) such as SnO, material based on zinc (Zn) such as ZnO, material based on titanium (Ti) such as TiO, and material based on phosphorus (P) such as P₂O₅) is detected between the back electrode **151** and the back surface field region **172** and between the back bus bar **152** and the back surface field region **172**.

Unlike in the present embodiment, in an alternative example, the emitter region **121** of the solar cell **1** may not have the selective emitter structure.

In this case, the emitter region **121** placed right under the anti-reflection region **130** has the same impurity doping concentration, impurity doping thickness, and surface resistance value as the emitter region **121** placed right under the front electrode region **140** because the anti-reflection region **130** is not placed. Accordingly, all the emitter regions **121** can have the same surface resistance value (e.g., about 50 Ω/sq. to 80 Ω/sq.) irrespective of their positions.

An operation of the solar cell **1** having the above structure according to the present embodiment is described below.

When light is radiated to the solar cell **1** and then incident on the substrate **110** via the anti-reflection region **130**, electrons and holes are generated from the semiconductor region by the light energy. At this time, the amount of light incident on the substrate **110** is increased because the reflection loss of light incident on the substrate **110** is reduced by the anti-reflection region **130**.

The electrons and holes are moved toward the emitter region **121** having the n type conductive type and the substrate **110** having the p type conductive type, respectively, by means of the p-n junction of the substrate **110** and the emitter region **121**. The electrons are moved toward the emitter region **121** as described above move to the second emitter parts **1212** via the first emitter parts **1211**, collected by the plurality of front electrodes **141** and the plurality of front bus bars **142**, and then moved along the plurality of front bus bars **142**. The holes moved toward the substrate **110** are collected by the back electrodes **151** and the plurality of back bus bars **152** adjacent to each other and are then moved along the plurality of back bus bars **152**. When the front bus bars **142** and the back bus bars **152** are coupled by the interconnector, current flows, and the current is externally used as power.

In this case, the amount of electric charges moved toward the front electrodes **141** is increased because the amount of electric charges lost is reduced by the emitter region **121** having the selective emitter structure, so that the efficiency of the solar cell **1** is significantly improved.

Furthermore, since the front electrode region **140** is formed by the plating method, the width of each of the front electrodes **141** is much smaller than the width (e.g., 80 μm to 120 μm) of each of the front electrodes fabricated using silver (Ag) paste by a screen-printing method. Accordingly, the area of the solar cell **1** on which light is incident is increased because an area where the front electrodes **141** that hinder the incidence of light are formed is reduced. Consequently, the efficiency of the solar cell **1** is improved.

Furthermore, when the selective emitter structure is formed, the second emitter region **1212** (i.e., a high concentration impurity doping region) is not placed under the entire front bus bar **142**, but is selectively placed under the front bus bar **142**, and the width of each of the front electrodes **141** is smaller than the width of the second emitter region **1212** placed under the front bus bar **142**. Accordingly, the high concentration impurity doping region is reduced, and thus the amount of electric charges lost by impurities is greatly reduced.

Furthermore, in the top surface of the anti-reflection region **130** including the first convex parts **21** and the first concave parts **22**, contact areas where the front electrode **141** comes in contact with the anti-reflection region **130** and where the front electrode **141** comes in contact with the emitter region **121** and contact areas where the front bus bar **142** comes in contact with the anti-reflection region **130** and where the front bus bar **142** comes in contact with the emitter region **121** are increased by the plurality of grooves **180** placed in the parts where grooves **180** come in contact with the front electrode region **140**. Accordingly, adhesive strength between the front electrode **141** and the anti-reflection region **130**, placed under the front electrode **141**, and between the front electrode **141** and the emitter region **121** and adhesive strength between the front bus bar **142** and the anti-reflection region **130**, placed under the front bus bar **142**, and between the front bus bar **142** and the emitter region **121** are improved.

A method of manufacturing the solar cell **1** according to an embodiment of the present invention is described below with reference to FIGS. **12a** to **12g**.

As shown in FIG. **12a**, the textured surface (i.e., the concave-convex surface) including the plurality of convex parts and the plurality of concave parts is formed in the front surface (i.e., a plane) of the substrate **110**, formed to have the first conductive type (e.g., the p type) and made of single crystalline silicon or polycrystalline silicon, by using a wet etch method or a dry etch method.

As shown in FIG. **12b**, the emitter region **120** including impurities [e.g., phosphorus (P)] having the second conductive type is formed on the front surface side of the substrate **110** formed to have the first conductive type (e.g., the p type) and made of single crystalline silicon or polycrystalline silicon. Here, the emitter region **120** may be formed using an ion implantation method or a thermal diffusion method, and the first conductive type region of the substrate **110** and the p-n junction may be formed in the emitter region **120**. The emitter region **120** may have a surface resistance value of about 80 Ω/sq. to 120 Ω/sq. Since the emitter region **120** is formed by implanting the impurities of the second conductive type into the substrate **110** as described above, the emitter region **120** is made of the same crystalline semiconductors as the substrate **110**, such as single crystalline silicon or polycrystalline silicon. Accordingly, the substrate **110** and the emitter region **120** form a homogeneous junction.

In an alternative embodiment, before the emitter region **120** is formed or after the emitter region **120** is formed, the textured surface having the plurality of convex parts and the plurality of concave parts may be formed in the front surface (i.e., a plane) of the substrate **110** [or a surface of the emitter region **120**] or the front surface and the back surface of the substrate **110** by using a dry etch method or a wet etch method, such as reaction ion etching. When the surface of the substrate **110** has the textured surface as described above, the amount of light incident on the substrate **110** is increased because an effect that the reflection of light incident on the substrate **110** is prevented is improved.

Next, as shown in FIG. 12c, the anti-reflection region 130 is formed over the emitter region 120 formed on the front surface side of the substrate 110 by using a Plasma Enhanced Chemical Vapor Deposition (PECVD) method. Here, the anti-reflection region 130 may be made of hydrogenated silicon nitrides (SiNx:H), hydrogenated silicon oxide nitrides (SiOxNy:H), hydrogenated silicon oxides (SiOx:H), or aluminum oxides (Al₂O₃).

Next, as shown in FIG. 12d, an impurity film 20 including impurities of the second conductive type is formed over the anti-reflection region 130 by using an inject-printing method, a spin-coating method, or a screen-printing method.

Next, as shown in FIG. 12e, the plurality of first and second opening regions 181 and 182 forming the emitter region 120 are formed in the anti-reflection region 130 by partially radiating a laser beam over the anti-reflection region 130.

The widths W41 and W42 of the first and the second opening regions 181 and 182 are identical with each other, and each of the widths W41 and W42 of the first and the second opening regions 181 and 182 may be about 5 μm to about 15 μm. The plurality of first opening regions 181 are the opening regions for forming the plurality of front electrodes 141 (i.e., the opening regions for the front electrodes), and the plurality of second opening regions 182 are the opening regions for forming the plurality of front bus bars 142 (i.e., the opening regions for the front bus bars).

Each of the first opening regions 181 is the opening region for forming each of the front electrodes 141. The first opening regions 181 are formed in the front electrode formation region AA where the front electrodes 141 will be formed in the anti-reflection region 130. The plurality of second opening regions 182 are the opening regions for forming the front bus bars 142. In order to form one front bus bar 142 having a width of about 1 mm to 1.5 mm as described above with reference to FIGS. 9 and 10, about 30 to 70 second opening regions 182 are formed in the front bus bar formation region AB of the anti-reflection region 130.

When the plurality of first and second opening regions 181 and 182 through which the emitter region 120 is exposed is formed over the anti-reflection region 130 by radiating the laser beam to the impurity film 20 as described above, the impurities of the second conductive type included in the impurity film 20 placed over the anti-reflection region 130 are further implanted and doped into the parts of the emitter region 120 exposed through the first and the second opening regions 181 and 182.

An object to radiate the laser beam is to form the plurality of first and second opening regions 181 and 182 at desired positions of the anti-reflection region 130 by removing desired parts of the anti-reflection region 130 and to further dope the impurities of the second conductive type into the desired parts of the emitter region 120.

Accordingly, the parts of the emitter region 120 exposed through the parts (i.e., the plurality of first and second opening regions 181 and 182) of the emitter region 120 to which the laser beam has been radiated have a higher impurity doping concentration than the remaining parts of the emitter region 120 to which the laser beam has not been radiated. Accordingly, the surface resistance value of the parts of the emitter region 120 is lower than the initial surface resistance value of the emitter region 120.

Accordingly, the parts of the emitter region 120 exposed through the plurality of first and second opening regions 181 and 182 have a surface resistance value (e.g., 10 Ω/sq. to 50 Ω/sq.) lower than the surface resistance value 80 Ω/sq. to 120 Ω/sq. of the emitter region 120.

After the operation of radiating the laser beam is finished, the emitter region 120 becomes the emitter region 121 of the selective emitter structure, including the first emitter parts 1211, placed under the anti-reflection region 130 and each formed to have a surface resistance value (i.e., a first surface resistance value) of about 80 Ω/sq. to 120 Ω/sq., and the second emitter parts 1212 placed in the parts of the emitter region 120 exposed through the plurality of first and second opening regions 181 and 182 and formed to have a surface resistance value (i.e., a second surface resistance value) of about 10 Ω/sq. to 50 Ω/sq.

The width W41 and W42 of the first and the second opening regions 181 and 182 may be the same as the widths W11 and W12 of the second emitter parts 1212, respectively, formed by the first and the second opening regions 181 and 182. The interval D11 between two adjacent second opening regions 182, from among the plurality of second opening regions 182 formed to form one front bus bar 142, may be the same as the interval D11 between two adjacent second emitter parts 1212 formed by the two adjacent second opening regions 182.

Next, the impurity film 20 remaining on the anti-reflection region 130 is removed by using hydrofluoric (HF) acid and pure water.

The plurality of first and second opening regions 181 and 182 formed in the anti-reflection region 130 by radiating the laser beam as described above is for contact between the emitter region 121 [i.e., the second emitter part 1212] and the plurality of front electrodes 141 and between the emitter region 121 and the plurality of front bus bars 142, when the plurality of front electrodes 141 and the plurality of front bus bars 142 are formed using the plating method.

As described above, a part of the anti-reflection region 130 where one front bus bar 142 will be placed is partially or selectively removed by using a laser beam in order to form each of the front bus bars 142, instead of fully removing the part of the anti-reflection region 130 where one front bus bar 142 will be formed by using a laser beam in order to form each of the front bus bars 142. Accordingly, the area of the anti-reflection region 130 to which the laser beam is radiated is reduced.

Accordingly, there are advantages in that the time taken to fabricate the solar cell 1 and a change in the characteristic of the solar cell 1 are reduced because the time taken to radiate a laser beam is reduced and a phenomenon in which the emitter region 121 or the substrate 110 are deteriorated by heat due to the laser beam is reduced.

Furthermore, the desired parts of the anti-reflection region 130 are removed by using a laser beam directly radiated to the anti-reflection region 130, instead of using an operation of removing the anti-reflection region 130 using etch paste or an additional mask. Accordingly, the width of each of the first and the second opening regions 181 and 182 that are formed is much smaller than that when the etch paste or the mask is used.

Accordingly, an area where the plurality of front electrodes 141 is formed is reduced because an area where the second emitter part 1212 (i.e., a high concentration impurity doping part) is formed is reduced and the width of the front electrode 141 is reduced.

In the present embodiment, the laser beam radiated to form the plurality of first and second opening regions 181 and 182 may have a wavelength of 532 nm, and power of the laser beam may be about 5 W to 20 W. Here, the power or the radiation time of the laser beam may be determined depending on a material or thickness of the anti-reflection region 130.

The side of each of the plurality of first opening regions **181** and each of the plurality of second opening regions **182**, formed by radiating the laser beam as described above, may have a plane or a concave-convex surface (i.e., a non-plane).

When both sides of the second emitter parts **12a** and **12b** exposed through the first and the second opening regions **181** and **182** have the plane, a laser beam used may have a stripe form having the same width as each of the first and the second opening regions **181** and **182**. When both sides of the second emitter parts **12a** and **12b** exposed through the first and the second opening regions **181** and **182** have the concave-convex surface, a laser beam used may have a spot form having the same width as each of the first and the second opening regions **181** and **182**.

When both sides of the second emitter parts **12a** and **12b** exposed through the first and the second opening regions **181** and **182** have the concave-convex surface, the area of the second emitter parts **12a** and **12b** exposed through the first and the second opening regions **181** and **182** is increased. Accordingly, a contact area where the front electrode **141** comes in contact with the second emitter parts **12a** and **12b** and a contact area where the front bus bar **142** comes in contact with the second emitter parts **12a** and **12b** are increased. When the first and the second opening regions **181** and **182** are formed using the laser beam having the stripe form, the time taken to form the first and the second opening regions **181** and **182** is reduced.

After the plurality of first and second opening regions **181** and **182** is formed in the anti-reflection region **130** in order to form the front electrode region **140** using a plating method as described above, the front electrode region **140** including the plurality of front electrodes **141** and the plurality of front bus bars **142** is formed by performing plating on the second emitter part **1212** exposed through the plurality of first and second opening regions **181** and **182**, as shown in FIG. **12f**. Here, an electroplating method or a Light-Induced Plating (LIP) method may be used as the plating method.

Accordingly, the plating is performed by precipitating a solution [e.g., $KAg(CN)_2$], containing relevant metal ions (e.g., silver (Ag) ions), into the second emitter parts **1212** of the emitter region **121** exposed through the plurality of first and second opening regions **181** and **182**.

As already described above with reference to FIGS. **10(a)** to **10(c)**, the top surface of each of the front electrodes **141** and the top surface of each of the front bus bars **142** have respective curved surface shapes according to a plating characteristic, and the plurality of opening regions **182** adjacent to one another is formed in order to form one front bus bar **142**. Accordingly, metals (i.e., parts of the front bus bars **142**) grown in the two second opening regions **182** adjacent to each other, respectively, from among the plurality of second opening regions **182** formed to form one front bus bar **142**, meet each other over the anti-reflection region **130**, thus forming one front bus bar **142**.

Accordingly, the width of each of the front bus bars **142** that are finally formed [i.e., the width of the bottom surface of each of the front bus bars **142** coming in contact with the anti-reflection region **130** and the emitter part **1212**] is greater than the width **D21** of the front bus bar formation region **AB**.

As described above, since the metal plating growth is isotropic growth, a top surface [i.e., a surface of the front bus bar **142** placed on the opposite side to the bottom surface] of the metal (i.e., part of the front bus bar **142**) plated on the basis of each of the second opening regions **182** also has a curved surface shape. Metal plating is performed on the basis of each of the two adjacent second opening regions **182**

and is overlapped with the anti-reflection region **130** placed between the two adjacent second opening regions **182**. Accordingly, the height of the top surface of the overlapping part of the metal grown by plating becomes higher than the height of the top surface of the metal part grown by plating on second emitter part **1212** exposed through the second opening region **182**.

Accordingly, the top surface [i.e., the surface of the front bus bar **142** placed on the opposite side to the bottom surface] of each of the front bus bars **142**, formed on the anti-reflection region **130** and on the second emitter part **1212** that are exposed through the second opening region **182** has a curved surface shape including the concave-convex surface having the plurality of convex parts and the plurality of concave parts.

Consequently, the surface roughness of the top surface of each of the front bus bars **142** is increased.

Each of the front electrodes **141** and each of the front bus bars **142**, included in the front electrode region **140** formed by the plating method as described above, are illustrated to have a single film structure made of metal, such as silver (Ag), but, in an alternative example, they may have a multi-film structure, such as a dual film or a triple film.

When each of the front electrodes **141** and each of the front bus bars **142** have a dual film structure, a lower film coming in contact with the emitter region **121** may be made of nickel (Ni), and an upper film placed on the lower film may be made of silver (Ag). Furthermore, when each of the front electrodes **141** and each of the front bus bars **142** have a triple film structure, a lower film coming in contact with the emitter region **121** may be made of nickel (Ni), a middle film placed on the lower film may be made of copper (Cu), and an upper film placed on the middle film may be made of silver (Ag) or tin (Sn).

Here, the lower film of each of the front electrodes **141** and each of the front bus bars **142** functions to improve an adhesion characteristic by reducing specific contact resistivity with the second emitter part **1212** coming in contact with the lower film. The middle film of each of the front electrodes **141** and each of the front bus bars **142** is for reducing costs and may be made of material having a low cost and excellent conductivity, such as copper (Cu). When the middle film is made of copper (Cu), the lower film placed under the middle film functions to prevent copper (Cu), having excellent bonding strength with silicon (Si), from functioning as impurities that penetrate into (or are absorbed by) the second emitter part **1212** made of silicon (Si) and thus hinder the movement of electric charges.

Furthermore, the upper film functions to prevent a film, placed under the upper film (e.g., the lower film or the middle film), from being oxidized and improve adhesive strength with a conductive tape placed over the upper film.

When the front electrode region **140** has a multi-layered film as described above, a multi-layered film sequentially having a desired thickness from the lower film to the upper film is formed using the plating method.

The film structure and material of the plurality of front electrodes **141** and the plurality of front bus bars **142** are the because the plurality of front electrodes **141** and the plurality of front bus bars **142** are formed at the same time using a plating process.

As shown in FIG. **12g**, back bus bar patterns **52** are partially formed in the back surface of the substrate **110**, corresponding to the front bus bars **142**, by printing paste containing silver (Ag) using a screen-printing method and then drying the paste. Furthermore, back electrode patterns **51** partially placed in the back surface of the substrate **110**

in which the back bus bar patterns **52** are not placed are formed by printing aluminum (Al), aluminum (Al)-silver (Ag), or paste containing silver (Ag) on the remaining back surface of the substrate **110** using a screen-printing method and then drying aluminum (Al), aluminum (Al)-silver (Ag), or the paste containing silver (Ag). Accordingly, back electrode region patterns **50** each including the back electrode pattern **51** and the back bus bar pattern **52** are completed.

Here, the back electrode pattern **51** is placed in part of an adjacent back bus bar pattern **52** and may be partially overlapped with the adjacent back bus bar pattern **52**, but may not be formed in the edge part of the back surface of the substrate **110**.

When the substrate **110** is a p type, the back electrode patterns **51** may be made of paste containing aluminum (Al). When the substrate **110** is an n type, the back electrode patterns **51** may be made of paste containing aluminum (Al)-silver (Ag) or paste containing silver (Ag).

Here, the back electrode patterns **51** and the back bus bar pattern **52** may be dried in a temperature of about 120° C. to about 200° C. An order that the back electrode patterns **51** and the back bus bar pattern **52** are formed may be changed.

Next, the substrate **110** in which the back electrode region patterns **50** are formed is subjected to a thermal treatment process in a temperature of about 750° C. to about 800° C.

Accordingly, the back electrode region **150**, including the back electrode **151** electrically connected to the substrate **110** and the plurality of back bus bars **152** connected to the substrate **110** and the back electrode **151**, and the back surface field regions **172** placed in the back surface of the substrate **110** coming in contact with the back electrodes **151** are formed (see FIGS. **1** and **2**).

In other words, the back electrode pattern **51** and the back bus bar pattern **52** of the back electrode region pattern **50** are chemically combined with the substrate **110** by means of the thermal treatment process. Thus, the back electrode pattern **51** and the back bus bar pattern **52** are formed into the back electrode **151** and the plurality of back bus bars **152**, respectively. Here, the back electrode pattern **51** and the back bus bar pattern **52** adjacent to each other are chemically combined, so that the back electrode **151** and the back bus bars **152** are electrically coupled.

Furthermore, during the thermal treatment process, aluminum (Al) or silver (Ag) included in the back electrode pattern **51** of the back electrode region pattern **50** is diffused into the substrate **110**, so that the back surface field region **172** (i.e., an impurity doping region) having a higher impurity concentration than the substrate **110** is formed in the substrate **110**. Thus, the back electrode **151** is brought in contact with the back surface field region **172** having higher conductivity than the substrate **110** and is electrically connected to the substrate **110**. Accordingly, electric charges from the substrate **110** are collected more easily.

In the present embodiment, since the emitter regions **121** are formed only in the front surface of the substrate **110**, an edge isolation process for blocking electrical connection with the emitter region placed in the back surface of the substrate **110** or an additional process for removing emitter regions formed in the back surface of the substrate **110** are not required. Accordingly, the productivity of the solar cell **1** is improved and manufacturing costs are reduced because the time taken to fabricate the solar cell **1** is reduced.

In the present embodiment, an example in which the front electrode region **140** including the plurality of front electrodes **141** and the plurality of front bus bars **142** is formed and the back electrode region **150** including the back electrode **151** and the plurality of back bus bars **152** is then

formed has been described. In an alternative example, the back electrode region **150** may be first formed, and the front electrode region **140** may be then formed.

As described above, since the plurality of front electrodes **141** is formed by plating, the width of each of the front electrodes **141** is smaller than the width of each of the front electrodes **141** when the plurality of front electrodes **141** is formed by using a screen-printing method. Accordingly, the area of the solar cell **1** on which light is incident is increased, and the efficiency of the solar cell **1** is improved.

Unlike in the present embodiment, when the emitter region **121** does not have the selective emitter structure (i.e., the emitter region **121** placed under the front electrode region **140** has the same surface resistance value as the emitter regions **121** other than the emitter regions **121** placed under the front electrode region **140** because the emitter regions **121** have the same surface resistance values irrespective of their positions), the process of FIG. **12d** in the processes described above is omitted.

In this case, after the anti-reflection region **130** is formed on the emitter region **120** of the substrate **110**, the plurality of first and second opening regions **181** and **182** is formed in the anti-reflection region **130** by directly radiating a laser beam over the anti-reflection region **130**.

Furthermore, an additional impurity film capable of further implanting impurities of the second conductive type into the emitter region **120** does not exist over or under the anti-reflection region **130**, and the object to radiate the laser beam is not for further doping the impurities of the second conductive type, but for removing only desired parts of the anti-reflection region **130**. Accordingly, an additional impurity doping process is not performed on the parts of the emitter region **120** to which the laser beam has been radiated.

Accordingly, the parts of the emitter region **120** to which the laser beam has been radiated and the parts of the emitter region **120** to which the laser beam has not been radiated have the same impurity doping concentration and surface resistance value.

As described above, the object to radiate the laser beam is different from the object described with reference to FIG. **12e**. Here, the radiated laser beam may have a wavelength of 355 nm. Furthermore, power (about 5 W to 20 W) of the laser beam or the time taken to radiate the laser beam is determined depending on the material or thickness of the anti-reflection region **130**.

In this case, the time taken to manufacture the solar cell **1** and costs necessary to fabricate the solar cell **1** are reduced because the processes of forming and removing the impurity film **20** are omitted.

In the present embodiment, the back electrodes **151** are made of paste containing aluminum (Al) or silver (Ag) by using a screen-printing method, and the back bus bars **152** are also made of paste containing aluminum (Al) or silver (Ag) by using a screen-printing method.

In an alternative embodiment, the back electrodes **151** and the back bus bars **152** are also formed using a plating method like the front electrodes **141** and the front bus bars **142**.

In this case, like the front electrode region **140**, the back electrodes **151** and the back bus bars **152** may be formed at the same time using the same plating process, and thus the back electrodes **151** and the back bus bars **152** may be made of the same material.

In addition, the back electrodes **151** and the back bus bars **152** may be formed simultaneously with the front electrodes **141** and the front bus bars **142** by using the plating process for the front electrodes **141** and the front bus bars **142**. In this

case, the material of the back electrode region **150** is the same as that of the front electrode region **140**. Furthermore, the back electrode region **150** may have not only a single film, but also a multi-film, such as a dual film or a triple film.

When the back electrode region **150** is formed by a plating method, the back electrode **151** and the back bus bar **152** have a dual film or a triple film. When a lower film is made of nickel (Ni), nickel silicide exists in the back surface field region **172** (i.e., between the part of the substrate **110** into which the impurities of the first conductive type have been doped at a high concentration and the back electrode **151** and between the substrate **110** and the back bus bar **152**), and a component of glass frit is not detected between the back electrode **151** and the substrate **110** [or the back surface field region **172**] and between the back bus bar **152** and the substrate **110** [or the back surface field region **172**].

FIGS. **12a** to **12g** illustrate the method of fabricating the solar cell **1** shown in FIGS. **1** and **2**. A method of forming the solar cell **1** shown in FIG. **11** is the same as the method described with reference to FIGS. **12a** to **12g** other than the number of second opening regions **182** for forming the front bus bar **142** and the width of the front bus bar **142**.

In other words, in the solar cell **1** shown in FIG. **11**, one second opening region **182** is necessary for one front bus bar **142**. Thus, the number of second opening regions **182** and the width of each of the second opening regions **182** have only to be changed in the process of forming the first and the second opening regions **181** and **182** shown in FIG. **12e**. Accordingly, the method of manufacturing the solar cell **1** shown in FIG. **11** is omitted.

A solar cell module fabricated by electrically connecting a plurality of the solar cells **1** using interconnectors is described below with reference to FIG. **13**.

The solar cell module **100** includes a plurality of solar cells **1** electrically connected by a plurality of interconnectors **210**, a passivation film **220** configured to protect the plurality of solar cells **1**, a transparent member **230** placed on the passivation film **220** placed on the light-receiving surface side of the plurality of solar cells **1**, and a back sheet **240** placed under a passivation film **220** placed on the opposite side to the light-receiving surface.

The solar cell module **100** may further include a frame for receiving the elements **210** to **240** integrated by a lamination process and a junction box for collecting power generated from the plurality of solar cells **1**.

The back sheet **240** functions to prevent moisture from being infiltrated from the back surface of the solar cell module **100** and thus to protect the plurality of solar cells **1** from an external environment. The back sheet **240** may have a multi-layer structure, including a layer for preventing the infiltration of moisture and oxygen, a layer for preventing chemical corrosion, and a layer having an insulating characteristic. The back sheet **240** may be made of opaque material.

The passivation films **220** are disposed under and on the plurality of solar cells **1** arranged in a matrix form, respectively, and are integrated with the plurality of solar cells **1** by a lamination process in such a way to surround the plurality of solar cells **1**. The passivation films **220** functions to prevent corrosion due to the infiltration of external moisture and to protect the plurality of solar cells **1** from shock. The passivation film **220** may be made of material, such as Ethylene Vinyl Acetate (EVA).

The transparent member **230** placed over the passivation film **220** is made of tempered glass having high transmittance and an excellent anti-breakage function. The tempered glass may be low iron tempered glass having low iron

component. The inside of the transparent member **230** may be subject to embossing processing in order to increase the scattering effect of light.

The electrical connection structure of the plurality of solar cells **1** included in the solar cell module **100** according to the present invention is described in detail with reference to FIGS. **14** and **15**.

The plurality of solar cells **1** included in the solar cell module **100** is arranged in a matrix form and coupled by the plurality of interconnectors **210** as shown in FIGS. **13** and **14**.

As shown in FIG. **15**, each of the interconnectors **210** includes conductive metal (e.g., copper (Cu)) **212** of unleaded material, containing a lead component of 1,000 ppm or lower, and solder (e.g., SnPbAg) **214** of leaded material that is coated on a surface of the conductive metal **212**. The material that coats the conductive metal **212** may be conductive metal (e.g., SnAg) not containing lead (Pb) and the interconnector **210** may be made of only the conductive metal **212**, according to circumstances.

As shown in FIG. **15**, each of the top surface and the bottom surface of the interconnector **210** has a curved surface not a plane. Accordingly, in the bottom surface of the interconnector **210** electrically connected to the front bus bar **142**, the central part of the interconnector **210** and the peripheral parts of the interconnector **210** are not placed in the same height, but they have a difference **H41** in height (e.g., FIG. **20**).

In two adjacent solar cells **1** placed in the same row, from among the plurality of solar cells **1** arranged in a matrix form, the front bus bars **142** placed in one of the two solar cells **1** are electrically and physically connected to the respective back bus bars **152**, placed in the other of the two solar cells **1**, through the interconnector **210**. Furthermore, in two adjacent solar cells **1** placed in the same column, from among the plurality of solar cells **1** arranged in a matrix form, the front bus bars **142** placed in one of the two solar cells **1** and not connected to the other of the two solar cells **1** are electrically and physically connected to the respective back bus bars **152**, placed in the other of the two solar cells **1** and not connected to the one of the two solar cells **1**, through the interconnector **210**.

A connection structure between the front bus bar **142** and the back bus bar **152** of the solar cell **1** using the plurality of interconnectors **210** as described above is described in detail below.

As described above, in the present embodiment, the front bus bar **142** and the back bus bar **152** are not directly connected to the respective interconnectors **210**, but are physically and electrically connected to the respective interconnectors **210** with respective conductive adhesion films **260** interposed therebetween.

As shown in FIG. **15**, the conductive adhesion films **260** and the interconnectors **210** are sequentially placed on the front bus bar **142** and the back bus bar **152**, respectively, and the conductive adhesion film **260** and the interconnector **210** are extended in a direction where the front bus bar **142** and the back bus bar **152** are extended.

In FIG. **15**, one front bus bar **142** and one back bus bar **152** are placed in the front surface and the back surface of the substrate **110**, respectively, and thus the number of each of the conductive adhesion films **260** and the interconnectors **210** placed in the front surface and the back surface of the substrate **110**, respectively, is one. The conductive adhesion film **260** and the interconnector **210** are placed in each of the plurality of front bus bars **142** placed in the front surface of the substrate **110**, and the conductive adhesion film **260** and

the interconnector 210 are placed in each of the plurality of back bus bars 152 placed in the back surface of the substrate 110. Accordingly, the number of front bus bars 142 placed in the front surface of the substrate 110 is the same as the number of each of the conductive adhesion films 260 and the interconnectors 210 placed over the front bus bars 142. The number of back bus bars 152 placed in the back surface of the substrate 110 is the same as the number of each of the conductive adhesion films 260 and the interconnectors 210 placed over the back bus bars 152.

As shown in FIGS. 16 to 19, the conductive adhesion film 260 includes resin 262 and a plurality of conductive particles 264 dispersed in the resin 262. The resin 262 may be made of any material having an adhesive property. It is preferred that thermosetting resin be used as the resin 262 in order to increase adhesion reliability. Only an example in which one front bus bar 142 and one interconnector 210 are coupled by the conductive adhesion film 260 is shown in FIGS. 16 to 19, for convenience of description. However, one back bus bar 152 and one interconnector 210 are coupled by the conductive adhesion film 260 as in FIGS. 16 to 19.

At least one kind selected from epoxy resin, phenoxy resin, acryl resin, polyimide resin, and polycarbonate resin may be used as the thermosetting resin.

The resin 262 may include a known hardener and a known hardening accelerator as specific ingredients other than the thermosetting resin. For example, the resin 262 may include reformed materials, such as a coupling agent based on silane, a coupling agent based on titanate, and a coupling agent based on aluminate, in order to improve an adhesive property between the front bus bar 142 and the interconnector 210 and between the back bus bar 152 and the interconnector 210. The resin 262 may further include a dispersing agent, such as calcium phosphate or calcium carbonate, in order to improve the dispersion property of the first conductive particle 264. The resin 262 may further include a rubber ingredient, such as acrylic rubber, silicon rubber, or urethane, in order to control the modulus of elasticity.

As shown in FIGS. 16 to 19, the conductive particles 264 include a plurality of first conductive particles 2641 each having a first thickness T1 and a plurality of conductive particles 2642 each having a second thickness T2 smaller than the first thickness T1. The plurality of first conductive particles 2641 and the plurality of second conductive particles 2642 are dispersed in the resin 262.

As shown in FIG. 16, the first thickness T1 of each of the plurality of first conductive particles 2641 may be smaller than a thickness T3 of the conductive adhesion film 260.

However, as shown in FIGS. 17 to 19, the first thickness T1 of each of the plurality of first conductive particles 2641 may be greater than the thickness T3 of the conductive adhesion film 260. In this case, at least part of each of the first conductive particles 2641 is protruded over the conductive adhesion film 260. In this case, the thickness T3 of the conductive adhesion film 260 is the same as the thickness of the resin 262.

In an alternative embodiment, in case of FIG. 16, the conductive particles 264 may include only one of the plurality of first conductive particles 2641 and the plurality of second conductive particles 2642. In case of FIGS. 17 to 19, the conductive particles 264 may include only the plurality of first conductive particles 2641.

When the conductive adhesion film 260 includes the first conductive particles 2641 each having a thickness greater than the thickness T3 of the conductive adhesion film 260, the front bus bar 142 and the interconnector 210 are elec-

trically and physically connected by only one first conductive particle 2641 because the thickness T1 of the first conductive particle 2641 is greater than the thickness T3 of the conductive adhesion film 260. Accordingly, electric charges collected by the front bus bar 142 are transferred to the interconnector 210 more excellently and stably.

In the plurality of first conductive particles 2641 and the plurality of second conductive particles 2642, each having a thickness smaller than the thickness T1 of the first conductive particle 2641 or the thickness T3 of the conductive adhesion film 260, as shown in FIGS. 16 and 19, at least two second conductive particles 2642 overlap with each other in up and down directions between the front bus bar 142 and the interconnector 210, thus forming a physical connection path between the front bus bar 142 and the interconnector 210. Accordingly, the at least two second conductive particles 2642 transfer electric charges, collected by the front bus bar 142, to the interconnector 210 through a connection path formed by the plurality of second conductive particles 2642, or the electric charges jump between the first and the second conductive particles 2641 and 2642 and move from the front bus bar 142 to the interconnector 210.

Accordingly, the electric charges placed in the front bus bar 142 move to the first and the second conductive particles 2641 and 2642 coming in contact with the front bus bar 142 or jump to adjacent first and second conductive particles 2641 and 2642 not directly coming in contact with the front bus bar 142, and the jump to adjacent first and second conductive particles 2641 and 2642 once or more, so that the electric charges move from the front bus bar 142 to the interconnector 210.

In the present embodiment, each of the thickness T1 of the first conductive particle 2641 and the thickness T2 of the second conductive particle 2642 may be about 2 μm to about 30 μm .

Each of the first conductive particle 2641 and the second conductive particle 2642 may be formed of a metal-coated resin particle, including at least one kind metal, selected from copper (Cu), silver (Ag), gold (Au), iron (Fe), nickel (Ni), lead (Pb), zinc (Zn), cobalt (Co), titanium (Ti), and magnesium (Mg), as a principle ingredient or may be formed of a metal particle including the above metal as a principle ingredient.

Each of the first and the second conductive particles 2641 and 2642 may have a circle or an oval shape as shown in FIGS. 16 and 17 or may have a radial shape as shown in FIGS. 18 and 19.

The term 'radial shape' refers to a shape of a metal particle in which a plurality of protrusion is irregularly formed on a surface of the metal particle having an approximately global shape.

When each of the first and the second conductive particles 2641 and 2642 has a circle or an oval shape, each of the thicknesses T1 and T2 of the first and the second conductive particles 2641 and 2642 may be the diameter (i.e., a minimum diameter in case of an oval) of each of the first and the second conductive particle 2641 and 2642.

When each of the first and the second conductive particles 2641 and 2642 is formed of a metal particle having a radial shape, each of the thicknesses T1 and T2 of the first and the second conductive particles 2641 and 2642 may be the shortest diameter measured from an approximately global shape formed by a virtual line that connects the ends of the plurality of protrusions formed in the surface of the metal particle.

The first and the second conductive particles 2641 and 2642, each made of a metal particle having a radial shape,

have lower specific contact resistivity than the first and the second conductive particles **2641** and **2642**, each having a circle or an oval shape, because a contact area where the first and the second conductive particles **2641** and **2642** come in contact with at least one of the front bus bar **142** and the interconnector **210** is increased.

In order to maintain stable connection strength and adhesive strength between front bus bar **142** and the interconnector **210** after the resin **262** is hardened, a mixing amount of the conductive particle **264** dispersed in the resin **262** may be 0.5 wt % to 20 wt % of a total volume of the conductive adhesion film **260**.

When the mixing amount of the conductive particle **264** is 0.5 wt % or higher, the movement of electric charges from the front bus bar **142** is performed more stably. When the mixing amount of the conductive particle **264** is 20 wt % or less, connection and adhesion with the front bus bar **142** are stably performed.

When the conductive adhesion film **260** is used for electrical connection between the front bus bar **142** and the interconnector **210** as described above, a tabbing process for attaching the conductive adhesion film **260** and the interconnector **210** over the front bus bar **142** includes a pre-bonding step (i.e., a first bonding step) of bonding the conductive adhesion film **260** to the front bus bar **142** of the solar cell **1** and a final bonding step (i.e., a second bonding step) of bonding the interconnector **210** and the conductive adhesion film **260**.

The pre-bonding step is performed to stably place the conductive adhesion film **260** on the front bus bar **142**. The final bonding step is performed to stably bond the conductive adhesion film **260** to the interconnector **210** placed over the front bus bar **142** so that the front bus bar **142** and the conductive adhesion film **260** and the front bus bar **142** and the interconnector **210** are stably coupled electrically and physically. Accordingly, a process temperature (i.e., a heating temperature) and pressure applied to the top of the conductive adhesion film **260** in the pre-bonding step are lower than a process temperature and pressure applied to the top of the interconnector **210** in the final bonding step, respectively.

For example, in the pre-bonding step, the heating temperature may be about 100° C. or lower, the pressure may be about 1 MPa. Furthermore, in the final bonding step, the heating temperature may be about 140° C. to 180° C., and the pressure may be about 2 MPa to 3 MPa.

Accordingly, the front bus bar **142** and the interconnector **210** are stably closely adhered to the conductive adhesion film **260** therebetween and are thus normally connected to the conductive adhesion film **260**. The back bus bar **152** and the interconnector **210** are also stably closely adhered to the conductive adhesion film **260** therebetween and are thus normally connected to the conductive adhesion film **260**.

Furthermore, the time for heating and pressurization in the pre-bonding step may be set approximately within 5 seconds. The time for heating and pressurization in the final bonding step may be set approximately within 10 seconds. In this case, the front bus bar **142**, the conductive adhesion film **260**, and the interconnector **210** are not damaged or deformed by heat.

When the front bus bar **142** and the interconnector **210** are coupled by the conductive adhesion film **260** as described above, the resin **262** of the conductive adhesion film **260** may be softened or melted by heat and pressure applied in the pre-bonding step and the final bonding step. In this case, at least part of at least one of the first and the second

conductive particles **2641** and **2642** included in the resin **262** enters at least one of the interconnector **201** and the front bus bar **142**.

Accordingly, in the state in which the front bus bar **142** has been bonded to the interconnector **210** by the conductive adhesion film **260**, each of a contact surface where the conductive particle **264** comes in contact with the interconnector **210** and a contact surface where the conductive particle **264** comes in contact with the front bus bar **142** becomes a non-plane, i.e., not a plane.

That is, as shown in FIGS. **16** to **19**, the conductive particle **264** is embedded in the interconnector **210** and the front bus bar **142**, and thus each of the interconnector **210** and the front bus bar **142** in which the conductive particle **264** has been embedded has the same surface shape as the conductive particle **264**.

When the interconnector **210** includes the conductive metal **212** and the solder **214**, at least some of the conductive particles **264** may be embedded up to the solder **214** of the interconnector **210** or may be embedded up to the conductive metal **212** via the solder **214**.

Here, the conductive particles **264** may be embedded in the interconnector **210** while being deformed into an oval by pressure applied when a tabbing task is performed as shown in FIG. **17** or may be embedded in the interconnector **210** in the state in which the conductive particle **264** maintains a circle as shown in FIG. **16**. The shapes of the conductive particles **2641** and **2642** may be changed when pressure is applied according to a difference between at least one of hardness and strength of the conductive particles **2641** and **2642** and at least one of hardness and strength of the interconnector **210**.

The conductive adhesion film **260**, the interconnector **210**, and the front bus bar **142** may be formed to have the same line width or may be made to have the same line width after the tabbing process is finished as shown in FIGS. **16** to **18** by controlling pressure during the tabbing process.

In an alternative embodiment, the conductive adhesion film **260** may be formed to have a greater line width than each of the interconnector **210** and the front bus bar **142**, or the conductive adhesion film **260** may be made to have a greater width than the front bus bar **142** after the tabbing process is finished as shown in FIG. **19** by controlling pressure applied during the tabbing process. Accordingly, the conductive adhesion film **260** covers both sides of the front bus bar **142**, and the conductive adhesion film **260** is placed at the ends of both sides of the front bus bar **142** and also on the adjacent anti-reflection region **130** according to circumstances. In this case, the front bus bar **142** and the interconnector **210** are bonded together more stably because a contact area with the conductive adhesion film **260** is increased, thereby increasing adhesive strength with the conductive adhesion film **260**.

Although not shown, in an alternative embodiment, the interconnector **210** and the front bus bar **142** may be formed to have a greater line width than the conductive adhesion film **260**.

When the front bus bar **142** and the interconnector **210** are connected using the conductive adhesion film **260** as described above, the front bus bar **142** and the interconnector **210** are more stably bonded without damaging or breaking the interconnector **210**.

In the present embodiment, the front electrode **141** and the front bus bar **142** have a curved surface shape, i.e., not a plane because the front electrode **141** and the front bus bar **142** are formed by plating. Accordingly, the height of a part in the central portion of each of the front electrodes **141** and

each of the front bus bars **142** is higher than the height in the edge part of each of the front electrodes **141** and each of the front bus bar **142**.

Accordingly, as described above, each of the top surface and the bottom surface of the interconnector **210** electrically coming in contact with the front bus bar **142** also has a curved surface, i.e., not a plane.

Accordingly, in a comparison example in which the interconnector **210** is attached right on the front bus bar **142** without using the conductive adhesion film **260**, the front bus bar **142** and the interconnector **260** are difficult to be bonded together because the top surface of the front bus bar **142** has a curved surface shape and the top surface and the bottom surface of the interconnector **260** have curved surface shapes.

In other words, in the case in which each of a surface (i.e., the top surface) of the front bus bar **142**, bonded to the interconnector **210**, and a surface (i.e., the bottom surface) of the interconnector **210**, bonded to the front bus bar **142**, has a curved surface shape, when one of the top surface of the front bus bar **142** and the bottom surface of the interconnector **210** has a concave curved surface and the other of the top surface of the front bus bar **142** and the bottom surface of the interconnector **210** has a convex curved surface and vice versa, bonding can be easily performed.

When the front bus bar **142** and the interconnector **210** are directly bonded together because both the top surface of the front bus bar **142** and the bottom surface of the interconnector **210** have convex curved surfaces as shown in FIG. **20(a)**, however, the central parts of the front bus bar **142** and the interconnector **210** come in contact with each other, but the peripheral parts of the front bus bar **142** and the interconnector **210** are spaced apart from each other by a specific interval **H51** without coming in contact with each other.

The interval **H51** between the front bus bar **142** and the interconnector **210** may be the sum of a difference **H41** between the heights of a central part of the interconnector **210** and a peripheral part of the interconnector **210** and a difference **H42** between the heights of a central part of the front bus bar **142** and a peripheral part of the front bus bar **142**.

Accordingly, when the interconnector **210** is bonded right on the front bus bar **142** by a soldering method using flux in the comparison example, the interconnector **210** is attached right on the front bus bar **142** by applying pressure to the interconnector **210** in a temperature of about 220° C. to 260° C.

Since the front bus bar **142** and the interconnector **210** are spaced apart from each other by the interval **H51** and the interconnector **210** is made of conductive metal that is less sensitive to heat than resin, cracks **2611** are generated in part of the interconnector **210** owing to applied pressure or defects **2612**, such as that part of the interconnector **210** is fallen apart, are generated [FIG. **20(b)**]. Furthermore, in FIG. **20(a)**, conductivity and a bonding area between the front bus bar **142** and the interconnector **210** are reduced because parts where the interconnector **210** and the front bus bar **142** are not stably bonded together occur owing to the interval **H51** between the front bus bar **142** and the interconnector **210**.

In addition, when applied pressure or heating temperature is increased in order to bond the peripheral parts of the interconnector **210** and the peripheral parts of the front bus bar **142** that are spaced apart from each other by the interval **H51** and are facing each other, there is a problem in that cracks are generated in parts already bonded together (e.g.,

the central part of the front bus bar **142** and the central part of the interconnector **210**) or the parts are damaged owing to excessive pressure, excessive temperature, etc. In some cases, at least one of the front bus bar **142**, the interconnector **210**, and the emitter region **121** may be deteriorated by heat.

In the present embodiment, however, as described above, the front bus bar **142** and the interconnector **210** are bonded together by using the conductive adhesion film **260** containing resin that is more sensitive to heat than conductive metal.

In this case, the resin **262** of the conductive adhesion film **260** is softened by heat applied in the pre-bonding step and the final bonding step, and the softened resin **262** has flexibility and a molding property much greater than the conductive metal.

Accordingly, when the conductive adhesion film **260** is closely adhered to the top surface of the front bus bar **142** and the bottom surface of the interconnector **210** by applied pressure, the softened resin **262** is smoothly molded along the surface shape of the top surface of the front bus bar **142** and the bottom surface of the interconnector **210**, both having the convex curved surfaces. Thus, the top surface of the front bus bar **142** and the bottom surface of the interconnector **210**, both having the curved surface shapes, and the conductive adhesion film **260** are stably bonded together.

Accordingly, since the flexibility and molding property of the resin **262** are increased by the softening phenomenon of the resin **262** as described above, adhesive strength between the conductive adhesion film **260** and the front bus bar **142** and a contact area where the conductive adhesion film **260** comes in contact with the front bus bar **142** and adhesive strength between the conductive adhesion film **260** and the interconnector **210** and a contact area where the conductive adhesion film **260** comes in contact with the interconnector **210** are increased. Furthermore, the occurrence of cracks in the interconnector **210** having a smaller flexibility and molding property than resin or a danger of breakage or damage to the interconnector **210** are significantly reduced or prevented.

Furthermore, when the front bus bar **142** and the interconnector **210** are bonded together using the conductive adhesion film **260** containing the resin **262**, the tabbing process using the conductive adhesion film **260** is performed in a temperature of about 100° C. to 180° C. as described above because the resin **262** has a much lower melting point than the conductive metal **212** or the solder **214**. When the interconnector **210** and the front bus bar **142** are directly bonded together as in the comparison example, however, the tabbing process is performed in a temperature of about 220° C. to 260° C.

Accordingly, a phenomenon in which the front bus bar **142**, the interconnector **210**, and the emitter region **121** are deteriorated is prevented because the process temperature of the present embodiment is much lower than that of the comparison example.

When the plurality of second opening regions **182** is used in order to form one front bus bar **142** as described above, the top surface of the front bus bar **142** coming in contact with the bottom surface of the conductive adhesion film **260** also has a curved surface shape. However, the roughness and flatness of the top surface of the front bus bar **142** are increased as compared with another embodiment in which one front bus bar **142** is formed using one second opening region **182** as described above. Accordingly, adhesive strength between the conductive adhesion film **260** and the front bus bar **142** is improved because the contact area where the front bus bar **142** comes in contact with the conductive adhesion film **260** is increased, as compared with another

embodiment in which one front bus bar **142** is formed using one second opening region **182**. Furthermore, the conductive adhesion film **260** and the front bus bar **142** are bonded together more stably and easily because of the increase in the flatness.

Although the connection structures between the front bus bar **142**, the conductive adhesion film **260**, and the interconnector **210** have been described above, the above description may also be likewise applied to connection structures between the back bus bars **152**, the conductive adhesion film **260**, and the interconnector **210**.

In the above description, a difference between numerical values (e.g., thicknesses and depths) due to a difference in the height between the plurality of convex parts **11** formed in the substrate **110** and the plurality of convex parts **21** formed in the anti-reflection region **130** may be disregarded, and different numerical values within the difference in the height may be assumed to be the same.

In the embodiments of the present invention, an example in which the plurality of front electrodes **141** and the plurality of front bus bars **142** are formed to penetrate the anti-reflection region **130** through the plurality of first and second opening regions **181** and **183** and are connected to the emitter region **121** has been described. In an alternative embodiment of a solar cell **1a** shown in FIGS. **21** to **23**, a plurality of front electrodes **141** is connected to an emitter region **121** through an anti-reflection region **130**, and a plurality of front bus bars **142a** is placed on the anti-reflection region **130**. Here, a part of each of the front bus bars **142a** is placed in a part to cross each of the front electrodes **141** is connected to the emitter region **121**.

In the solar cell **1a** shown in FIGS. **21** to **23**, parts having the same structures as those of the solar cells **1** shown in FIGS. **1** and **2** are assigned the same reference numerals, and a detailed description thereof is omitted.

For this, unlike in the solar cells **1** shown in FIGS. **1** and **2**, as shown in FIGS. **21** to **23**, each of opening regions **181** through which part of the emitter region **121** is exposed is placed only under each of the front electrodes **141**, and the plurality of opening regions **182** does not exist under each of the front bus bars **142a**.

Accordingly, as shown in FIG. **23**, the opening regions **181** are spaced apart from one another and are formed in the same direction. Here, positions where the plurality of opening regions **181** is formed correspond to respective positions where the plurality of front electrodes **141** is formed, and a direction where the plurality of opening regions **181** is extended is identical with a direction where the plurality of front electrodes **141** is extended.

In the solar cell **1a** according to the alternative embodiment, a second emitter part **1212** having a higher impurity concentration than a first emitter part **1211** is placed only under each of the front electrodes **141**, but is not placed under each of the front bus bars **142a**. Thus, only the plurality of front electrodes **141** is connected to the second emitter part **1212**, and the plurality of front bus bars **142a** is connected to the anti-reflection region **130**. Furthermore, since each of the first opening regions **181** where each of the front electrodes **141** is placed is also formed in the part to cross each of the front bus bars **142a**, each of the front bus bars **142a** is connected to the emitter region **121** (i.e., the second emitter part **1212**) in the part to cross each of the front electrodes **141**.

In FIG. **23**, however, the first opening region **181** may not be placed in the part where the front electrode **141** crosses the front bus bar **142a**. In this case, one opening region **181** for one front electrode **141** is not continuous, but is cut in the

part where the front bus bar **142** is placed. In this case, each of the front bus bars **142a** is not connected to the emitter region **121** both in the part where the front bus bars **142** does not cross each of the front electrodes **141** and in the part where the front bus bars **142** crosses each of the front electrodes **141**, but is placed on the anti-reflection region **130** and is directly brought in contact with the anti-reflection region **130**.

Each of the front electrodes **141** has the same structure as that shown in FIGS. **1** and **2** because electrode plating is performed on the front electrodes **141** as described above. Accordingly, each of the front electrodes **141** may have a single film made of silver (Ag) or may have a multi-layered film, such as a dual film, including a lower film made of nickel (Ni) and an upper film made of silver (Ag), or a triple film, including a lower film made of nickel (Ni), a middle film made of copper (Cu), and an upper film made of silver (Ag) or tin (Sn).

The front bus bars **142** may be formed by a screen-printing method employing conductive paste containing metal material, such as silver (Ag).

Each of the front electrodes **141** and each of the front bus bars **142** may have the same height or different heights. After the plurality of front electrodes **141** each including at least one film is formed using a plating method, the plurality of front bus bars **142** may be formed using a screen-printing method. In an alternative embodiment, after the plurality of front bus bars **142** is formed, the plurality of front electrodes **141** may be formed.

When the first opening region **181** is also formed in the part where each of the front electrodes **141** crosses each of the front bus bars **142a** as shown in FIG. **23**, only the front electrode **141** may exit. In an alternative embodiment, however, when the first opening region **181** is also formed in the part where each of the front electrodes **141** crosses each of the front bus bars **142a**, a film for the front electrode **141** formed by plating and a film for the front bus bar **142a** formed by a screen-printing method may exist at the same time. Here, the order of the film formed by the plating and the film formed by the screen-printing method may be changed according to the order in which the front electrode **141** and the front bus bar **142** are formed.

In this case, the surface of each of the front bus bars **142** has a concave-convex surface because the height of a part of the front bus bar **142a** where the front bus bar **142a** crosses the front electrode **141** is higher than the height of a part of where the front bus bar **142a** does not cross the front electrode **141**. Furthermore, a contact area where the front bus bar **142a** comes in contact with an interconnector is increased because the surface area of the front bus bar **142a** is increased. In addition, since specific contact resistivity is reduced in a part where the front bus bar **142a** is connected to the front electrode **141**, electric charges are more easily moved from the front electrode **141** to the front bus bar **142a**.

While the invention has been shown and described with respect to the preferred embodiments, it will be understood by those skilled in the art that various changes and modifications may be made without departing from the spirit and scope of invention as defined in the following claims.

What is claimed is:

1. A solar cell module, comprising:

a plurality of solar cells each comprising a substrate having a first conductive type, an emitter region having a second conductive type which is opposite to the first conductive type and on the substrate, an anti-reflection region on the emitter region, a plurality of first elec-

trodes in a first direction and electrically connected to the emitter region through a plurality of first opening regions in the anti-reflection region, a first bus bar crossing the plurality of first electrodes in a second direction and electrically connected to the emitter region through a plurality of second opening regions in the anti-reflection region, a plurality of second electrodes electrically connected to the substrate, and a second bus bar electrically connected to the plurality of second electrodes;

a conductive metal interconnector to electrically connect the first bus bar and the second bus bar of an adjacent solar cell of the plurality of solar cells; and

a conductive adhesion film between the first bus bar and the second bus bar and the interconnector, and contains a plurality of conductive particles dispersed in resin to electrically connect the first bus bar and the second bus bar and the interconnector,

wherein the anti-reflection region comprises the plurality of first opening regions through which parts of the emitter region are exposed, the plurality of second opening regions through which parts of the emitter region are exposed, and a plurality of grooves which are spaced apart from the second opening regions and expose a portion of the insulator or the emitter region, wherein the plurality of first electrodes are formed through the first opening regions by metal plating, and wherein the first bus bar is in the plurality of grooves.

2. The solar cell module as claimed in claim 1, wherein a resistance value of the exposed emitter region of the first opening region is greater than a resistance value of another emitter region.

3. The solar cell module as claimed in claim 1, wherein one of the plurality of conductive particles has a thickness greater than or equal to a thickness of the conductive adhesion film.

4. The solar cell module as claimed in claim 1, wherein one of the plurality of conductive particles is embedded in one of the interconnector and the first electrodes or the second electrodes.

5. The solar cell module as claimed in claim 1, wherein one of the plurality of conductive particles has a thickness smaller than a thickness of the conductive adhesion film.

6. The solar cell module as claimed in claim 5, wherein two or more of the plurality of conductive particles have a direct contact with each other to have direct contact with one of the interconnector and the first electrodes or the second electrodes.

7. The solar cell modules as claimed in claim 5, wherein two or more of the plurality of conductive particles have an indirect contact with each other to have indirect contact with one of the interconnector and the first electrodes or the second electrodes.

8. The solar cell module as claimed in claim 1, wherein the conductive particles are formed of a metal-coated resin particle including one selected from the group consisting of copper (Cu), silver (Ag), gold (Au), iron (Fe), nickel (Ni), lead (Pb), zinc (Zn), cobalt (Co), titanium (Ti), and magnesium (Mg), as ingredients.

9. The solar cell module as claimed in claim 1, wherein the conductive particles are formed of a metal particle made including one selected from the group consisting of copper (Cu), silver (Ag), gold (Au), iron (Fe), nickel (Ni), lead (Pb), zinc (Zn), cobalt (Co), titanium (Ti), and magnesium (Mg).

10. The solar cell module as claimed in claim 1, wherein one of the plurality of conductive particles has a circle, an oval, or a radial shape.

11. The solar cell module as claimed in claim 1, wherein one of the conductive particles has irregular or protruded portions.

12. The solar cell module as claimed in claim 1, wherein the conductive metal comprises a lead component of 1,000 ppm or less.

13. The solar cell module as claimed in claim 1, wherein the interconnector further comprises solder coated on a surface of the conductive metal.

14. The solar cell module as claimed in claim 1, wherein one of the first electrodes and the second electrodes comprises an uneven surface.

15. The solar cell module as claimed in claim 1, wherein nickel silicide is included between the substrate and one of the first electrodes and the second electrodes.

16. The solar cell module as claimed in claim 1, wherein one of the first electrodes and the second electrodes is formed by the metal plating such that at least one curved surface shape is formed.

17. The solar cell module as claimed in claim 1, wherein one of the first electrodes and the second electrodes comprises:

- a first film on the substrate including nickel (Ni), and
- a second film on the first film including silver (Ag) or copper (Cu).

18. The solar cell module as claimed in claim 17, further comprising a third film on the second film including silver (Ag) or tin (Sn) when the second film is made of copper (Cu).

19. The solar cell module as claimed in claim 1, wherein a first surface of one of the first electrodes and the second electrodes in contact with the conductive adhesion film has a convex curved surface.

20. The solar cell module as claimed in claim 1, wherein a height at a center of the conductive adhesion film is less than a height at an edge of the conductive adhesion film.

21. The solar cell module as claimed in claim 1, wherein depths of the plurality of grooves are less than depths of the first and the second opening regions.

22. The solar cell module as claimed in claim 1, wherein the insulating layer anti-reflection region is between the plurality of grooves and the first and the second opening regions, and a portion of the first bus bar directly contacting the insulating layer anti-reflection region does not contact the emitter region.

23. The solar cell module as claimed in claim 1, wherein the first electrodes and the first bus bar comprise a plurality of layers.

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